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JANUARY, 1945

RADIOACTIVITY AND ORGANIC CONTENT OF SOME PALEOZOIC SHALES[1]

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Cambridge, Massachusetts

ABSTRACT

By measurement of the total beta activity, the total alpha activity and the radium content, a new method has been developed for the routine determination of radioactive substances in sedimentary rocks. The important radioactive elements in these rocks are uranium, thorium, and potassium. Earlier work by Beers and Goodman has shown that these radioactive elements may be found largely in three principal *loci:* (1) in association with the heavy minerals of sands and sandstones, (2) in K^{40}, the active isotope of potassium which is found in evaporites, oil-field brines, clastic fragments of micas and other potassium-bearing minerals, and in clays and shales which may contain up to 6.5 per cent potassium, (3) in the uranium and thorium content of shales and clays, impure limestones and marls, shaly sandstones, and organic sediments.

Pure limestones and pure quartz sands are found to exhibit practically no measurable radioactivity. Black shales containing up to 16 per cent organic matter have been found to contain high concentrations of the three principal radioactive elements. Excellent correlations are shown to exist between the uranium content, the thorium-uranium ratio and carbon content in individual shale formations.

These studies throw new light on three important problems: (1) the sedimentation environment of Paleozoic black shales, (2) the evolution of petroleum source beds, (3) the relationship of radioactive and organic matter in these beds.

INTRODUCTION

The natural radioactivity of terrestrial materials is of interest to the geologist because of important chemical reactions produced by radiations from the uranium and thorium series. Of special interest to the petroleum geologist is the pos-

[1] Presented before the Association research committee at Dallas, March 21, 1944. Manuscript received, October 1, 1944.

[2] Department of geology, Massachusetts Institute of Technology.

The coöperation of The Pure Oil Company and many of its representatives in furnishing material for these measurements deserves recognition. Theron Wasson and Ira H. Cram have been most generous in their provision of carefully selected well cuttings free from contamination. Acknowledgment is also due to Carl C. Addison, Myron C. Kiess and Lynn K. Lee. Thanks are due to Professor Warren J. Mead, who has made possible the program at the Massachusetts Institute of Technology, for his continued encouragement and support. A detailed description of the apparatus and methods of measurement and calibration is the subject of another paper by Beers and Goodman (3). R. B. Giles, Jr., made the carbon analyses and part of the radium determinations. Special thanks are due Professor Clark Goodman, C. W. Sheppard, and R. M. Tripp for their detailed criticism in the preparation of the manuscript.

sible effect which these radiations may have on the origin and evolution of oil. It has been suggested that the migration of underground fluids might be traced by radioactivity measurements. Gamma-ray well logs are now of established value in geologic studies. Their implications will be better understood when the geological distribution of radioactive elements has been more fully determined. One of the purposes of this paper is to evaluate the radioactive materials found in certain Paleozoic shales.

Although the contents of radioactive elements in igneous rocks have been determined by many observers, relatively little has been done on sedimentary rocks, especially those which may be source beds or reservoir rocks of petroleum (1–3).[3] It has been shown (3) that the important radioactive substances, uranium, thorium and potassium, may be found largely in the following three principal *loci* in sediments.

1. The first *locus* is with the heavy minerals of sands and sandstones. In 1932 Clark and Botset (4) showed a similar correlation between radon and the heavy-mineral content of soils.

2. A second source of activity is in K^{40}, the active isotope of potassium. The highest concentrations are found in sedimentary evaporites. Certain oil-field brines have appreciable potassium content (5). Sediments containing clastic fragments of micas and other potassium-bearing minerals exhibit activity in proportion to their potassium content. The most widespread occurrence of potassium is in clays and shales which contain up to 6.5 per cent.

3. The third *locus* of radioactivity is in the uranium and thorium content of shales and clays, impure limestones and marls, and other sediments containing large colloidal fractions. Pure limestones or pure quartz sands exhibit practically no measurable radioactivity.

Shales comprise 82 per cent of the sedimentary rocks of the earth (6). As previously observed (3), they also contain the largest concentrations of radioactive substances. When considered together, these two facts emphasize the importance of detailed studies on shale bodies. The relatively high organic content of certain Paleozoic black shales further accents the need of searching for possible genetic relationships. The present research has been divided between a general study of the distribution of the radioactive elements in these *loci* and a detailed study of the radioactive content of certain Paleozoic shales.

APPARATUS AND METHODS OF MEASUREMENT

Three types of radiation are emitted by radioactive elements, namely, alpha, beta, and gamma rays, as shown schematically in Figures 1, 2, and 3. The electrical effects produced by these radiations serve as a sensitive means of measurement. Each type of radiation has its particular range of applicability. For rapid measurement of rock samples, the beta rays offer a number of distinct advantages.

[3] Numbers in parenthesis indicate references at end of this article.

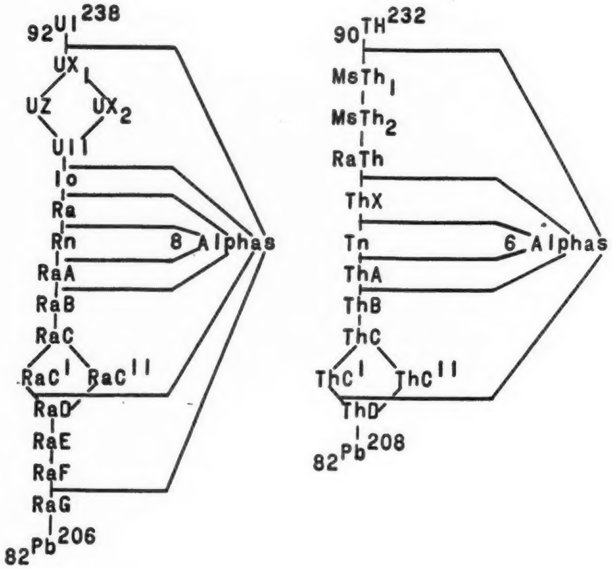

FIG. 1.—Important terrestrial alpha emitters.

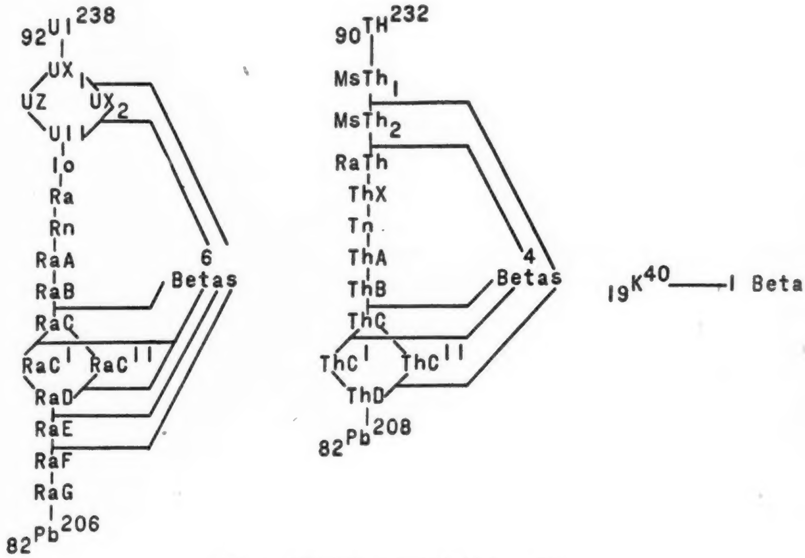

FIG. 2.—Important terrestrial beta emitters.

Only a few grams of sample are needed instead of the several kilograms required for gamma-ray measurements. The treatment of the sample is very simple. A single measurement occupies only a few minutes instead of the several hours required for alpha-ray measurements. Active samples must be confined for 30 days or longer before measurement in order to establish equilibrium between radium and its decay products.

Measurements of potassium activity can be directly related to concentration of potassium alone since there is only one radioactive isotope, K^{40}, and the

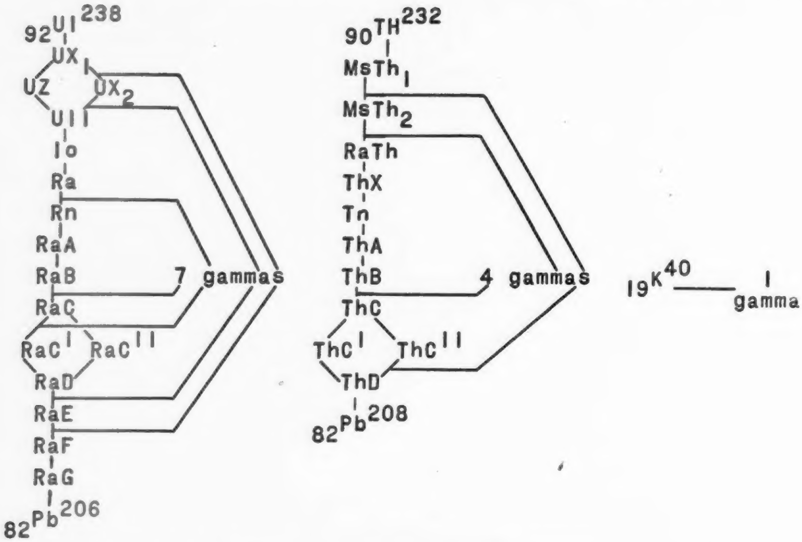

FIG. 3.—Important terrestrial gamma emitters.

abundance of K^{40} is constant (12, 13). Although potassium also emits 2 Mev gamma rays, the ratio of the number of these rays to the number of beta rays emitted is only about 3:100. This fact must be borne in mind in attempting to compare the results of beta-ray measurements with gamma-ray well logs. For rocks whose age is greater than one million years, it can generally be assumed that the uranium and thorium series are in equilibrium. Under these conditions the total number of alpha, beta, or gamma rays emitted per unit of time by either series is directly proportional to the concentration of any individual member of that series.

The direct fusion method (14) has been employed in determining the radium content of rock samples in this research. Assuming equilibrium, the uranium is computed from these measurements. Thorium has been determined by difference from measurements of the total alpha activity and the separate radium determination (11).

The present technique employs a bell-type Geiger counter with a thin mica window (Fig. 4). A counting-rate-meter type of amplifier and recorder was used (7, 8).

The counters employed in this work were calibrated empirically by the use of standard rock samples of densities and activities found in well cuttings. Pure crystalline KCl was used as a source of potassium calibration. Analyzed Brazilian monazite sand was used for thorium. Carnotite ore certified by Ledoux and Company of New York City was used in the uranium standards. The thorium and

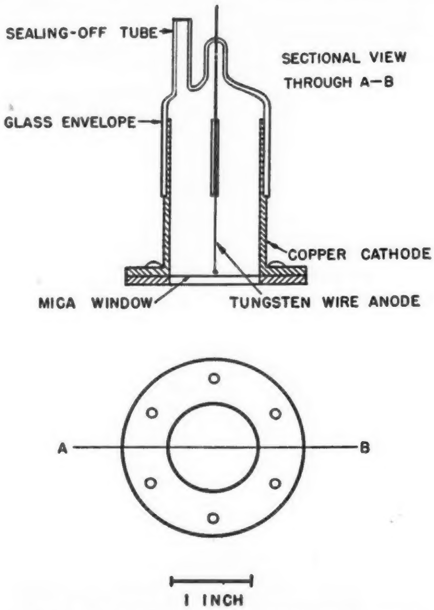

FIG. 4.—Schematic diagram of beta-ray counter.

uranium minerals were contributed by Professor Robley D. Evans, and were a part of the same standards used in his gamma-ray studies of terrestrial materials (9). Calibration curves for potassium, uranium and thorium over a range of densities were obtained[4] (Fig. 5).

As previously reported (3), a good estimate of potassium can be made as follows. Measurement of the total alpha-activity gives the sum of uranium and thorium alpha radiation. Because of compensating effects in these two series, the beta activity equivalent to a measured alpha activity is essentially independent

[4] Because of the statistical distribution in the number of beta particles recorded by the counter each minute, it is necessary that observations be taken over a sufficient period of time to reduce the experimental uncertainty to a satisfactory value. Most samples yield an uncertainty of less than 10 per cent in a measurement of 20–30 minutes. A graphic milliameter connected to the output of the counting rate meter records these fluctuations.

of whether the radioactivity is from the uranium series or the thorium series alone. Hence the potassium beta activity represents the difference between observed total beta activity and the equivalent beta activity calculated from the measured alpha activity. As a further aid in calibration, the series of rock stand-

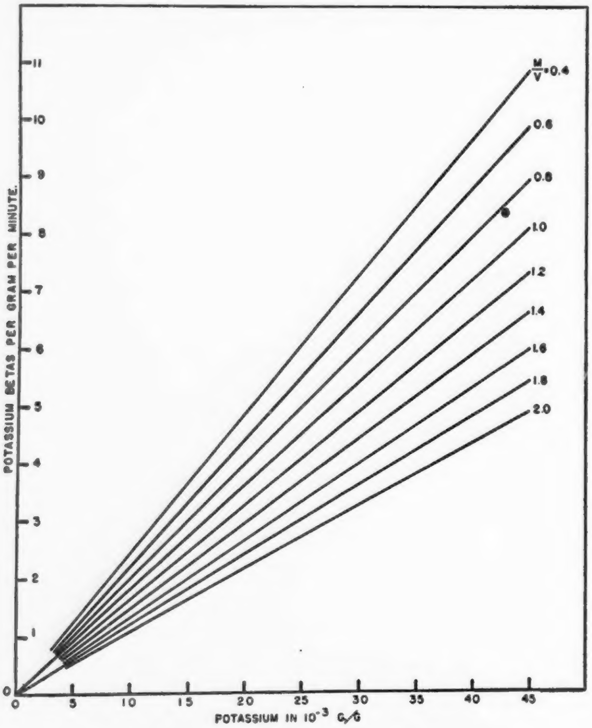

FIG. 5.—Calibration of beta-ray counter for potassium.

ards established by the National Research Council Committee on Standards of Radioactivity (16) was used.

Quantitative analyses for carbon and hydrogen were made by dry combustion. The sample is burned in an atmosphere of pure oxygen. Carbon dioxide and water vapor resulting from the combustion are collected separately by selective absorption. Corrections were not made in all the measurements for nitrogen, sulphur, and water of composition and crystallization. Preliminary work showed that corrections for nitrogen and sulphur are negligible in these Paleozoic black shales. The results reported herein are correct for total carbon content. It is assumed, as established by P. D. Trask (17), that organic matter in these shales is

proportional to carbon content. The dry combustion method is independent of the carbonate content of the samples.

RESULTS OF MEASUREMENTS

Figures 6 and 7 show the results of measurements on well cuttings from The Pure Oil Company's Gingrich No. 3, Osceola County, Michigan. Sample determinations were made by R. E. Beeker. These cuttings were analyzed for uranium content, carbon, hydrogen, total alpha activity, total beta activity. The potassium content of some of them was determined by chemical analysis by S. J. Tyree.

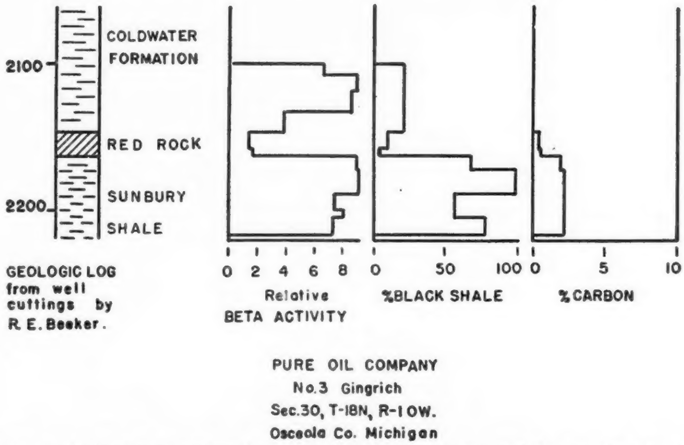

FIG. 6.—Analysis of well cuttings from Pure Oil Company's Gingrich No. 3, Osceola County, Michigan, Coldwater and Sunbury formations.

Figure 6 shows three interesting features. The Coldwater formation is nearly 100 per cent micaceous shale. Its relatively high beta activity indicates the presence of potassium-bearing minerals, since the uranium and thorium content are not large enough to account for all the betas. The carbon content has not yet been determined, but it can be estimated from the per cent of black shale.

The Coldwater red rock is quite different from the overlying gray shale. It contains 50 per cent red calcareous shale up to 75 per cent light gray limestone. The significant feature is its dominantly calcareous composition and relatively low dark shale content.

The Sunbury formation is more than 95 per cent dark gray to black shale with some pyrite. Its carbon content is about 2 per cent.

Figure 7 shows measurements on the Antrim black shale with portions of the adjacent formations to illustrate the contrast in rock types. The carbon content ranges from 5 to 10 per cent, several times that of the Sunbury black shale. Detailed measurements of the Antrim were made at 2,738–2,750 feet and 2,800–

2,823 feet. These samples furnished many of the data on which important conclusions have been based. Other detailed studies were made on The Pure Oil Company's Small No. 3, and cuttings of the Chattanooga, Woodford, and Sylvan shales from wells in Oklahoma.

The values of thorium content reported here have been determined by differences. In samples whose potassium content is accurately known from chemical

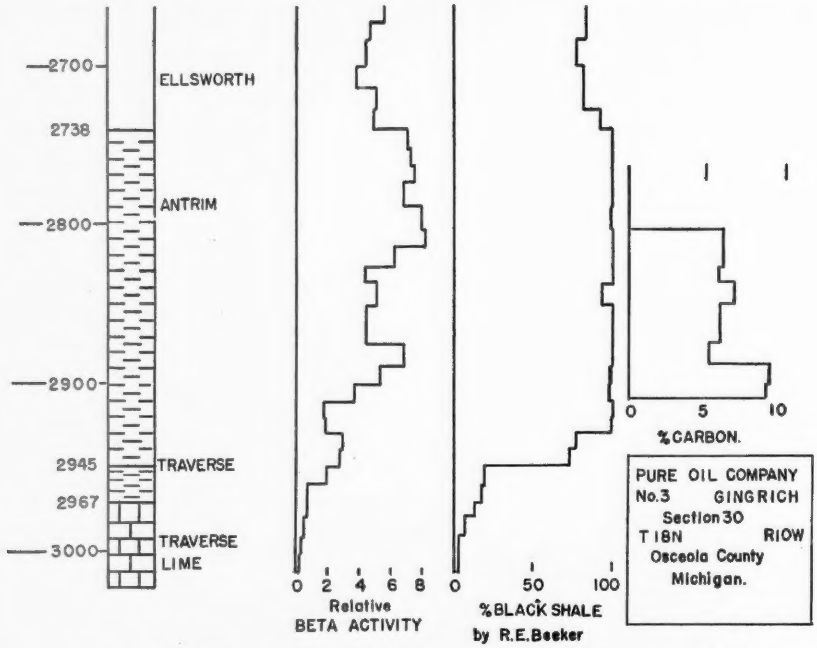

FIG. 7.—Analysis of well cuttings from Pure Oil Company's Gingrich No. 3, Osceola County, Michigan, Antrim and adjacent formations.

analysis, the betas emitted by K^{40} can be subtracted from the total observed betas. The remainder is that due to uranium and thorium. By reference to Figure 8, the total apha activity can be determined for these two elements. A separate uranium determination reveals how many alphas are contributed by uranium, the balance comes from thorium. The thorium content is thus computed by differences. For those samples not having potassium analyses, thorium may be determined from the total alpha activity, but the computations are subject to the same objection. This method is, therefore, not entirely satisfactory, as the probable error of successive differences increases with the number of computations. Work is now in progress on a direct determination of thorium which may remove this difficulty.

It is the interaction between the organic matter buried in the sediments and the radiations of uranium and thorium to which we must now turn our attention. Three types of radiation are given off by natural radioactive elements. Alpha-rays are helium atoms with two positive charges. They are emitted from the radioactive atom at an initial velocity varying from 8,000 to 12,000 miles per second (1.3 to 2.0×10^9 cm./sec.), possessing enormous kinetic energy. As they travel in their straight line paths through atoms of matter, they ionize and produce chemical reactions (Fig. 9). They are the most potent projectiles of all

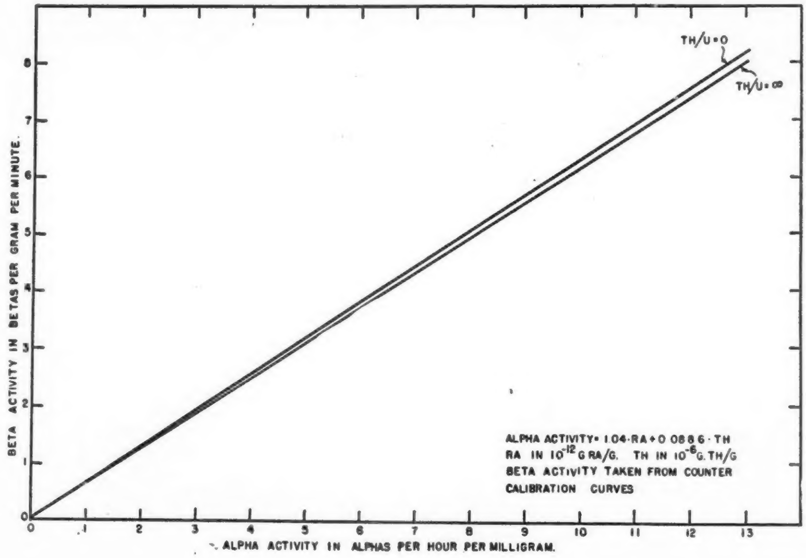

FIG. 8.—Calculated beta *versus* alpha activity.

nuclear radiations. Over 90 per cent of the atomic energy which propels chemical reactions resides in the alpha rays. Their range in air at standard conditions is up to about 7 centimeters. If they are released in regions of higher pressure, such as source beds of petroleum, they accomplish their work of ionization in a shorter distance, but their total effect is the same. Among the chemical reactions which have been produced in the laboratory by alpha rays is the decomposition of water into hydrogen and oxygen.

Alpha rays also react upon hydrocarbons to produce other hydrocarbons and release hydrogen. Methane reacts to produce ethane, propane, butane, pentane and others, with the evolution of hydrogen. S. C. Lind (15) reports that no gaseous olefines were discovered in the reaction of alpha particles upon methane, ethane, propane, or butane. The reaction on ethane, propane and butane tends

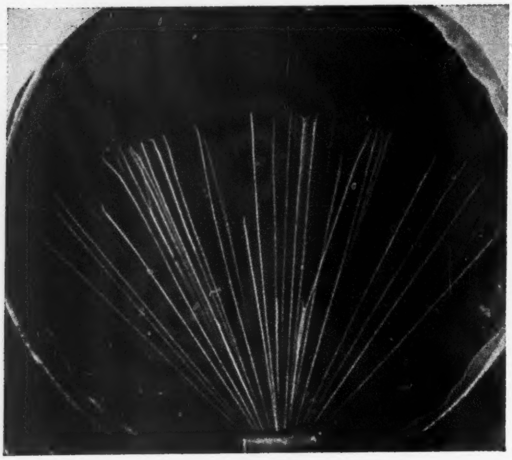

FIG. 9.—Tracks of alpha rays from polonium (radium F). From Rasetti, *Elements of Nuclear Physics*, Prentice-Hall, Inc.

TABLE I

DISTRIBUTION OF RADIATIONS IN SOME PALEOZOIC ROCKS

Formation *Depth in Feet*	*Total Alphas Per* *Minute Per Gram*	*Total Betas Per* *Minute Per Gram*
Cold Water 2,144–2,147	14.7± 1.2 U= 10.0 Th= 4.7	3.75±0.39 K=3.17 U=0.39 Th=0.19
Red Rock 2,147–2,162	13.9± 0.5 U= 7.8 Th= 6 1	1.54±0.01 K=1.22 U=0.18 Th=0.14
Sunbury 2,163–	52.4± 0.8 U= 25.6 Th= 26.8	8.96±0.01 K=6.42 U=1.51 Th=1.03
Antrim 2,738–2,945	404.1± 12.2 U=148.8 Th=255.3	21.4 K=9.63 U=8.97 Th=2.80
Traverse limestone 2,967–	5.2± 1.4 U= 4.7 Th= 0.5	1.15 K=0.73 U=0.36 Th=0.06

to liberate methane and hydrogen as well as the other gaseous hydrocarbons previously mentioned. The hydrogen thus evolved does not react with the other products, according to Lind.

In addition to these processes, alpha particles may also cause polymerization of gaseous unsaturates into liquids and solids. In the presence of oxygen, hydrocarbons can be converted into other hydrocarbons, and they can also be oxidized.

The conversion effect of beta and gamma radiations from uranium and

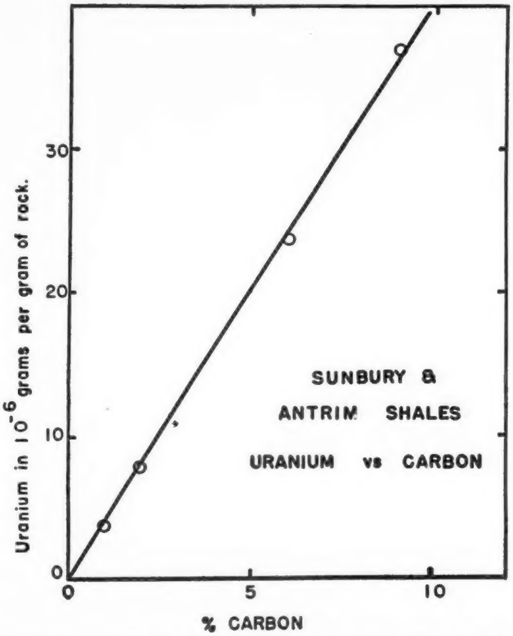

FIG. 10.—Uranium content *versus* carbon content in some Paleozoic shales.

thorium is very small. The recoil of radioactive elements after the emission of alpha particles may develop ionizing energy amounting to perhaps 2 per cent of the total.

When we know how much conversion to expect from a gram of radium, then we must turn to the sedimentary rocks, to see how much radioactive matter is available for these reactions. Table I shows the results of a few detailed studies of uranium, thorium, and potassium in Paleozoic rocks. These charts show a rough correlation between radioactivity and carbon content. Figure 10 shows how well this correlation stands out when uranium is plotted against carbon. We must remember that in ancient sediments it is the original uranium and thorium which

are responsible for the important reactions. These are the elements which have been the primary source of alpha emitters throughout geologic time.

We must examine Figure 10 with caution so as not to draw too many inferences from it. There is an excellent correlation between uranium and carbon content of the Sunbury and Antrim black shales. In any one shale formation there is not much variation in the uranium and organic content. The two uppermost points were taken from the Antrim, the third lower from the Sunbury and the lowest from the transition zone. This graph really means that the chemical environment at the time of sedimentation of the Sunbury and Antrim must have had common factors. Points taken from formations of other ages and conditions of sedimentation do not fall on this graph. Within a particular sedimentary environment we can draw certain conclusions.

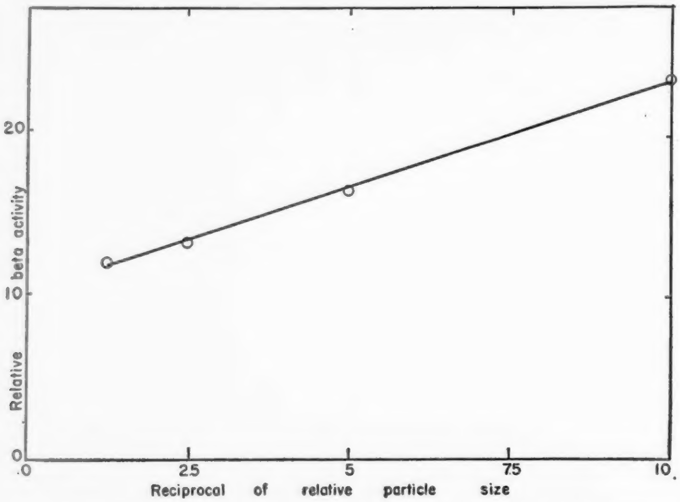

FIG. 11.—Uranium content *versus* particle size in some Paleozoic shales.

The correlation between carbon and uranium is supported by a similar one between carbon and the fineness of particle size (Fig. 11), the thorium-uranium ratio, the potassium content, and, to a smaller degree, the total alpha activity and the total beta activity. Several of these quantities may be used as indices of the sedimentation environment of the particular rock to which they apply. Our special interest here is the significance which they lend to source beds of petroleum.

GEOLOGICAL DISCUSSION

The evolution of Paleozoic source beds is closely related to that of the black shales. Most of these shales now possess residual organic matter from which

hydrocarbons can be obtained by thermal distillation or solvent extraction. This organic matter should not be confused with that in the so-called oil shales, which are believed to have been deposited in an entirely different environment than the source beds of petroleum. There are two aspects of the problem which deserve our attention. The first of these is to determine how well the facts of radioactivity agree with established hypotheses of the evolution of black shales. The second is to discover if the relationship of radioactivity and organic matter is favorable for the genesis of petroleum.

The development of prevailing concepts of Paleozoic black shales has been recorded in published reports by Ulrich (18), Schuchert (19), Grabau (20), Twenhofel (21), Ruedemann (22), Woolnough (23), and others. Recent descriptions of typical Paleozoic shales and the probable manner of their development have been published by Hard (24), Tarbell (25), Hale (26), and others. These black shales are found throughout the geologic column, the blackness being largely caused by organic matter, which may be the decomposition products of cellulose or lignin, while in other cases it is largely of colloidal nature. Some black shales contain spores, spore cases, pollen grains and the decomposition products of algae, which originally were composed of fats, waxes, gums, and resins. Brooks (27) has listed the following as possible types of organic matter which may be converted into petroleum: (1) proteins, (2) cellulose, (3) lignins, (4) oleo resins, (5) waxes, and (6) fatty oils. He concludes that fatty oils are the most important of all materials. They might be expected to oxidize under the aerobic conditions of shallow water and become widely disseminated as soft amorphous solids throughout the sediment. Such shales are called bituminous, many contain marine fossils. Examples are found in the Utica shale of New York, the Sunbury and the Antrim of Michigan, and the Chattanooga and Sylvan of the Mid-Continent. Twenhofel (21) observes that there may have been several distinct ways in which these black shales may have developed. He classes them as follows.

1. In deep salt water appendages of the ocean, like the Black Sea.
2. In deep holes of shallow water bodies.
3. In shallow lagoons, bays and sounds of tideless seas.
4. In barred or nearly land-locked basins separated from the open seas by visible or submarine barriers, preventing effective circulation, preferably surrounded by lands of little relief and under climatic conditions not permitting inflow of fresh water into the basins to exceed the loss due to evaporation, so that there must be inflow from the sea.
5. Over plant covered bottoms of tideless shallow epicontinental sea.

Hard (24) expresses the opinion that the upper Devonian bituminous shales of New York were deposited in comparatively shallow water, the source of sediments being on the east. They are characterized by a uniform fine-grained deposit of colloidal organic and inorganic material, planktonic remains being plentiful in places. During the deposition of the black shale series a definite zone of demarcation was present between the shallow and comparatively fresh water of the east and the slightly deeper and more saline water of the west. Hard reports that the bituminous content of these shales seems to be directly related to the

type of organic material, and this particular type of decay existed only where the water was truly saline and toxic conditions were present.

Clarke (28) describes the sediments of the Black Sea as consisting of very fine black mud, with separation of FeS, abundant remains of planktonic diatoms and with fragments of young lamellibranchs.

Evidently the Paleozoic epicontinental seas of North America were oscillatory, for they tend to finger in and out at their feather edges into sediments of different nature. At times of structural upwarping on the east, fresh deposits of clastic fragments were brought into the shallow sea. Off shore at some distance, still in a region of relatively shallow water, the black organic matter was being deposited from water whose saline content was less than that of the deep ocean to the west. During the deposition of the fine-grained shales, the landmass forming the source of these sediments was evidently without great relief. It had been nearly base levelled. Because of the quantity of sedimentary material composing the shales it is clear that the landmass had been subjected to erosion over a long period of time. The residual soil may have been very deep. When the land topography was younger clastic materials and soluble minerals had been removed from the rocks and carried away to the ocean. As stream gradients declined the residual material was worked over by weathering agencies which removed the soluble constituents. Left behind were those minerals which either resist decomposition or are stable products of the weathering environment. The resistant minerals include many of the heavy residues, among them the oxides of uranium and thorium. The residual soil thus developed a high concentration of these radioactive substances, which remained in place until the land was flooded by the transgressing epicontinental sea.

The minerals in equilibrium with the weathering environment are largely what we know as clay minerals. These include the kaolin group, certain micas, and the montmorillonite group which are prominent in fuller's earth and bentonites. This special group of sedimentary minerals is the result of chemical metamorphism (weathering) of other minerals found in all types of rocks. They comprise the great bulk of sedimentary clays and shales, and are characterized by their colloidal dimensions and the electric charge borne by many of them. Their dimensions range from a few to several hundred millimicrons in diameter, and the thickness of an individual crystal is of the order of a few millimicrons. They have perfect basal cleavage, and are commonly deposited with all basal planes parallel, thus resulting in an impervious layer of clay. If flocculated by an electrolyte such as sea water, they may be deposited in random positions and result in a clay of extremely high porosity, as high as 97 per cent. The spaces between individual particles may be filled with water, in which are dissolved and suspended soluble salts and organic and inorganic colloids.

COLLOIDS AND ADSORPTION

It has been known for many years that uranium compounds readily go into

the colloidal phase. Under certain special conditions thorium compounds behave likewise. Lindgren (29) is of the opinion that most deposits of uranium ores, such as pitchblende and carnotite, were colloidal aggregations. Paneth (30), Hahn (31), and others have demonstrated that uranium salts go into colloidal dispersion before the solubility product of the salt is reached. Britton (32) has shown experimentally that thorium nitrate or thorium sulphate in solution will precipitate if the pH of the solution exceeds 3.7. The precipitation of uranium salts varies with their concentration, since they go into a stable colloidal dispersion so readily.

Here we have experimental evidence which may help to interpret the sedimentary environment under which black shales have been deposited. The limited number of thorium determinations made under this program reveals that the Antrim shale has a high thorium-uranium ratio. One agency responsible for the sedimentation of thorium in excess of uranium might be a pH in excess of 3.7 in the shallow sea. Evans and Goodman (10) have shown that the average thorium-uranium ration of source rocks is close to 4.0. The value observed for the Antrim is about 8.0. Evidently some selective agency has been at work tending to remove thorium from solution or colloidal suspension in excess of uranium.

It is known that organic colloids may be effective in stabilizing in organic colloidal dispersions (32). The addition of 0.3 gram of sugar to 100 cubic centimeters of water containing colloidal thorium oxide stabilizes the dispersion up to a pH of 10. The same amount of sugar gave even greater stability to colloidal dispersions of uranium oxide. Gelatine behaves similarly in equal concentration.

It is known that uranium may form compounds with organic substances or become adsorbed to them. A good example of this behavior is given by the deposits of thucholite found in actual association with oil in a pegmatite dyke in Ontario. This mineral contains 20 per cent hydrocarbons and more than 50 per cent fixed carbon. Thucholite occurs as a pseudomorph of uraninite. Spence (33) observes that thucholite has been formed by the radioactive reaction on the oil with eventual replacement of carbon for uranium.

One more factor regarding the relationship of clay minerals and radioactivity must be noted. Preliminary experiments by R. B. Giles, Jr., have shown that certain clay minerals in sedimenting out of colloidal dispersion will adsorb large portions of uranium and thorium salts in solution or suspension. There is a slight indication that thorium may be preferentially adsorbed over uranium. It is evident also that the adsorption of organic matter may influence this co-precipitation.

DISCUSSION OF RESULTS

The foregoing details give a general idea of how radioactive substances and organic matter are related to one another. If all of these elements inhabit a colloidal dispersion at one time, then we have a mechanism which may account for the widespread and uniform distribution of radioactive substances and the correlative organic matter in these black shales. We can also account for the cor-

relation of these indices with the fineness of the shale texture. Experimental evidence that radioactivity increases with fineness of texture of the Antrim shale is shown in Figure 11. It illustrates the selective action of the colloidal environment on the distribution of radioactivity and organic matter.

Since the thorium-uranium ratio in these black shales exceeds the average value observed by Evans and Goodman (10) for source rocks in general, one might form an opinion as to the probable importance of organic colloids in this sedimentation environment. The pH of the shallow Antrim sea must have exceeded 3.7, the point at which thorium oxide is normally precipitated. Yet all the thorium could not have been precipitated immediately after dispersion, as evidenced by its vertical and lateral persistence in the section. It is permissible, therefore, to believe that thorium salts were retained in suspension long enough after dispersion to permit their lateral distribution in the shallow Antrim sea over relatively great distances. The presence of organic colloids may have stabilized the dispersed thorium salts so long as the salinity of the water remained low. The stabilizing effect of 0.3 per cent sugar or gelatine suggests that observed concentrations of organic colloids in neritic zones may reasonably be supposed to exert a similar influence.

The rôle of potassium in this picture is consistent with all that has been stated (34). It has been observed that the dominant clay mineral found in ancient shales (illite or hydromica) contains potassium in its structure. Two potassium ions are incorporated in each illite crystal and additional potassium is adsorbed to the broken edges and corners. The potassium content of these clays may be as high as 6.5 per cent. Much of it is the result of colloidal segregation from dissolved potassium salts. Considerable adsorption took place before the minerals were washed into the sea. This occurs in normal soils which have not been rendered sour by prolonged leaching with acid.

We may now summarize these factors into an hypothesis for the distribution of the Sunbury and Antrim shales with their high content of uranium, thorium, potassium, and organic matter. The thickest section of black shale occurs at the eastern edge of the basin, nearest the source of the sediments. From the Traverse to the Coldwater there is a complete cycle of sedimentary rock types, giving evidence of the period of warping that went on from upper Devonian through Mississippian time.

The Traverse limestone indicates relatively deep, clear water marine environment. It was followed by a transition period, during which the sediments included increasing amounts of shallow water clay materials. Evidently the landmass on the east was rising, bringing to the sea the residual soil left behind from the long period of erosion. As the upwarp continued, the sediments changed to the clastic type of the Berea sand, but during intervening Antrim time all the sediments were of black shale type.

The early development of the black muds is indicated by the transition zone in the upper Traverse. From the thick section of the underlying Traverse lime-

stone, one would conclude that the lands on the east were relatively quiet during this time, permitting the development of deep soils with high concentrations of uranium, thorium, and potassium minerals. Prolonged weathering resulted in an abundance of clay material of small particle size. As the sea transgressed the land, the residual débris was carried into the sea, gradually at first, and evidently with considerable fresh water. The colloidal material was dispersed and the process of selection by adsorption followed. The larger sizes were sedimented at the edge of the sea. Finer materials were disseminated by normal diffusion and Brownian motion. Some sedimentation probably occurred, though at a slow rate, in the warm fresh waters near the shore. Organic matter undoubtedly developed according to its adaptability to the environment. Colloids may remain in suspension for a long time, but eventually the larger fractions sediment, even under the stable environment described.

The departure from these conditions took place at the zone where shallow fresh water became deeper and more saline. This zone may have migrated back and forth laterally with the oscillations of the sea. Some colloidal material accelerates its rate of sedimentation as soon as the salt content of the water becomes appreciable, of the order of 5,000 parts per million. Other fractions continue to remain in suspension, according to their particle size, their organic composition, and their colloidal nature. Some hydrophilic colloids remain in stable dispersion in electrolytes, so long as they retain their water hulls. Most organic colloids belong in this class. Other colloidal particles continue the process of distribution in fresh water, until the increasing saline content neutralizes their electric charge and they sediment to the bottom. At the time of sedimentation clay particles take with them their adsorbed uranium, thorium, and potassium, along with whatever organic matter might come into their influence. These materials would also sediment independently, in accordance with their response to environment.

The oscillation of the sea, the uplift and subsidence of the landmass providing the source of the sediments, may have combined to spread deposits laterally in addition to the process of diffusion. Evidence for the tectonic cycle is given by the sequence of sediments already noted. At the close of Antrim time, the eastern edge of the basin became the strand line. Clastic sediments were deposited here as the Berea sandstone. Evidently this marks the time of maximum upwarping. The Berea is followed by the Sunbury shale, suggesting a return, with further levelling, to conditions much like those in Antrim time. This similarity will be remembered from the graph of uranium and carbon content shown in Figure 10. The ensuing Coldwater shale, with its high calcareous content, marks the end of a period of downwarping of the basin and maximum development of marine conditions in this locality. The Coldwater red rock and other lenses of pure limestone are good indices of these conditions. The low radioactivity and organic content of this formation will be remembered.

If clay minerals, organic matter, and radioactive elements are concentrated in shales as suggested, there is good reason to think that their interaction may be

favorable for petroleum genesis. From the viewpoint of the physicist, C. W. Sheppard (35) has provided an excellent summary of the known facts and their relationship in this problem. In addition he has shown how computations may be made of the possible quantity of hydrocarbons converted by radioactive elements reacting with favorably disposed organic matter. By using Sheppard's method for uniformly distributed uranium, thorium, and organic matter found in the Antrim shale, the following computations can be made.

$$\begin{aligned} dM/dt &= (\Delta M/\Delta N)\times C\times[2.0\times 10^{10}U+5.6\times 10^{9}\times Th] \\ &= 1\times 0.16[2.0\times 10^{10}\times 28\times 10^{-6}+5.6\times 10^{9}\times 273\times 10^{6}] \\ &= 121{,}500+244{,}400 \\ &= 36\times 10^{4} \text{ molecules per second per gram of sediment,} \end{aligned}$$

where: dM/dt = number of molecules converted matter per second per gram of sediment.

C = organic content in grams per gram of sediment.
= 1.6 × carbon content.

U = uranium content of sediment in grams uranium per gram sediment.

Th = thorium content of sediment in grams thorium per gram sediment.

$\Delta M/\Delta N$ = molecules converted matter per ion pair produced = 1.

If a mean molecular weight of 250 is assumed for the organic material, about 0.004 gram of organic matter would be converted per gram of sediment in one million years, or roughly $2\frac{1}{2}$ per cent. In 40 million years all of the 16 per cent observed organic matter could have been converted into other products.

These figures represent the most favorable conditions observed in these studies of Paleozoic shales. Possible conversion values range downward from those given here to the figure given by Sheppard ($\frac{1}{3}\times 10^{-4}$ gram or 0.001 per cent). Allowance should be made for the water content at the time of conversion, and, if an average value of 50 per cent is assumed, the time required for complete conversion into other materials amounts to 80 million years.

EFFECTS OF MIGRATION

Once conversion has set in, the behavior of the products of the reaction becomes of importance. If these products remain at the place where they were originally attacked, the ensuing reactions to alpha particles will be different from that which takes place after they have migrated away. For help in the interpretation of this problem we turn to established theories of petroleum migration and accumulation. This takes us into controversial subject matter (36, 37, 38), but whether we accept the gravitational, the hydraulic or the replacement theory, or some composite of them, we must consider the facts common to all of them.

For the migration of substantial quantities of petroleum we must have adequate carriers of the migrating substances. These may be gases or liquids, and the

corresponding permeability will control the extent and direction of migration. A search of the published record reveals the generally held opinion that liquid hydrocarbons can not move in any substantial quantity through shales after burial and compaction. Gases migrate in microscopic quantities through rocks after lithification. Therefore, we may place an upper limit on the time which the original organic endowment may have spent in the source bed, beginning with its initial sedimentation. This is the time during which any transforming agency may have reacted with the organic matter.

There is the possibility that some alteration and conversion of organic matter and petroleum takes place during migration. The shale bed through which the material is being moved during compaction contains many of the essential materials and conditions which were responsible for the initial generation of petroleum. There seems to be no reason for thinking that the transforming agency must stop its activity because the object of attack is on the move. Only when the organic matter is out of the source bed is the influence of that particular environment at an end. The probability is strong that the period of time just delimited is less than all subsequent geologic time.

There is another possibility, however. If the organic matter or any substantial part of it migrates with the transforming agency to the reservoir rock, then a much greater geologic time is available for the final evolution of petroleum. Under this assumption the conversion and alteration process may go on until one or the other of the substances is exhausted.

When the conversion capacity of alpha particles on solid organic matter is known, we may be able to make some computations on the probability that a substantial quantity of petroleum has been generated by radioactivity. An important factor in these computations is the geologic time available. It is entirely possible that the minor fraction of time spent by this matter in source beds will be inadequate for the genesis of any appreciable amount of oil. In that event we are faced with two choices: either (1) radioactivity has not produced much oil, or (2) it has done its work through the entire geologic period since sedimentation. Even this period of time may be inadequate.

If we must choose the second alternative, we encounter another dilemma. Many prolific reservoir rocks show almost no measurable radioactivity. The Simpson sand is a good example, yet the oil of this sand was shown by Bell, Goodman, and Whitehead (1) to have significant radioactive content. Their measurements did not reveal the quantity of uranium in solution and suspension, so we are not able at the moment to determine what may be present here.

One further effect may be noted. Recent developments in catalytic refining have shown that clay minerals are significantly active in contact with petroleum. Catalytic hydrogenation and polymerization of oils have been demonstrated in the use of fuller's earth as a decoloring and filtering agency. We must recall Lind's observation that alpha particles also condense petroleum hydrocarbons. It is rank speculation to extrapolate these effects into source beds and carrier

beds of petroleum. It is no help to researchers on this problem to bring in the worn-out factor of immense geologic time. Therefore, we can only suspend judgment on this point until experiments give some indication of what may be going on of this nature in clays and shales.

CONCLUSION

Before making unrestricted conclusions on the significance of the foregoing computations, the reader should pause to evaluate many of the factors involved. A great deal of tradition has developed in connection with some of these concepts. As a consequence it is tempting to one unfamiliar with the history of their development to draw too favorable results from this picture. It is hoped the following criticism may temper the enthusiasm of those who may think that the origin of oil has been uniquely portrayed in this discussion.

In any estimate of the amount of petroleum that may have been formed by any agency, we return again and again to the question of original organic endowment. The present research, as well as that of Trask and others, deals blithely with the *present* organic content. In this paper, Trask's value of 1.6 for the ratio of organic to carbon content has been taken at face value. It is outside the scope of this paper to evaluate this figure. Whether it is 1.0 or 2.0 or some intermediate value is not of immediate importance. An attempt has been made merely to see if the order of magnitude of converted materials would warrant further work on the problem. Under the assumptions, it seems likely that a significant amount of converted materials may have been produced. If variations in limits change the figures by a factor of 2 or 3, then the results are different by the same amount. In any event there remains the possibility that radioactivity has contributed something substantial in the process of conversion.

The relationship of *present* organic content to that available for conversion into petroleum is not known. It may be equal to it, more than or less than the original endowment. Organic matter in the form of hydrocarbons may have migrated into the source bed at different times throughout its history. If so, this material also may have been acted upon by the conversion agencies and altered. Some of the products of the reactions undoubtedly migrated away from their original place, only to encounter other sources of activity and suffer further alteration. One might properly consider the entire source bed as a place where reactions and migration were taking place continuously, even as the products of conversion moved along to their ultimate destination.

Unless the net reaction favors condensation and polymerization as opposed to cracking, there is the probability that the net mass of added material is small. Lighter constituents, especially gases, would migrate more easily away from the point where they were attacked, leaving behind heavier residues for further alteration. Present measurements on the Antrim shale show that the quantity of radioactive material has not diminished to such a low value that alteration cannot continue at least at the rate dictated by *present* concentrations. The residues

would therefore continue to receive the impact of alpha bombardment. If the products of these reactions were fluid, they might continue to move away from the source bed so long as permeability was sufficient. We come then to a possibility that the present organic content can not exceed the original organic endowment very much. As a matter of speculation, the present matter may be less than that originally present. In that case we have made a conservative estimate of the contribution which radioactivity has made to the alteration of organic matter.

Much additional work needs to be done on this problem. Foremost among the requirements is the separation and identification of the organic matter found in these black shales. Work is already in progress on this point. Preliminary analyses have indicated that they may contain much free carbon. If this is true, there arises the question whether it was of organic origin. Studies should be made of recent sediments whose nature and environment duplicate those postulated for the black shales of ancient origin. In particular, the organic matter of these recent deposits should be measured and analyzed. Radioactivity measurements of such deposits have not, to date, shown activities comparable with those found in ancient sediments. There is a great need for samples of bottom sea deposits from the marine and neritic black shale environments. The writer would greatly appreciate receiving such samples for analysis. References given at the end of this paper suggest likely localities where these samples might be collected.

SUMMARY

Measurement of the organic content and radioactivity of certain Paleozoic black shales sets forth the possibility that a significant amount of organic matter may have been altered by alpha-particle bombardment. The original organic endowment is related to the present contents in an unknown manner. The products of the alteration are not known. Experiments elsewhere may show that these products are petroleum constituents as we know them from our limited knowledge of this subject. Since the probability is good that radioactive substances have made a significant contribution to the conversion of organic matter in shales, further work is warranted.

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GROUND WATER AND GEOLOGIC STRUCTURE OF NATCHITOCHES AREA, LOUISIANA[1]

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ABSTRACT

The municipal water supply of the city of Natchitoches has been obtained for many years from shallow wells screened in fine-grained sands of the Wilcox formation. These sands have been overdeveloped and the supply of water stored in the sands has been depleted gradually as the recharge from rainfall has failed year by year to equal the withdrawals by wells. An exploratory program designed to locate an adequate supply of ground water was initiated in the fall of 1943 by the City of Natchitoches. This program, directed by the Geological Survey, United States Department of the Interior, included the drilling, electric logging, and testing of nine exploratory wells which penetrated water sands of the Sparta sand and of the Wilcox formation.

Geological and hydrological data obtained from the test drilling suggest that the city of Natchitoches may be situated on a downthrown fault block defined on the southwest by a fault along Youngs Bayou and on the southeast by a fault extending from Old River toward Cane River Lake. Salt water, unlike connate sea water in composition, is present in the sands underlying most of the city. A similarity of topographic, geologic, and hydrologic conditions in this area to those in salt-dome areas in near-by parishes is evident.

Southwest of the city, abundant supplies of soft water were found in the Sparta sand and in the sands of the Wilcox formation. These sands crop out in a narrow band extending from Natchitoches into Texas, and generally yield moderately large quantities of potable water in the areas immediately south of their outcrops. A supply of at least 1,000,000 gallons a day for the city of Natchitoches may be obtained from three to five properly developed supply wells in Secs. 10, 56, and 57, T. 8 N., R. 7 W. Additional water for increased needs of the future may be provided by extending this well field toward the west.

INTRODUCTION

Ground-water investigations were begun in Natchitoches in March, 1941, by the Geological Survey, United States Department of the Interior, in coöperation with the Louisiana Department of Conservation, and the City of Natchitoches to determine the advisability of drilling additional water wells within the city limits. This study, made by J. C. Maher and T. B. Stanley, Jr., was completed in September, 1941, and the results indicated that, although large quantities of hard water are available from the Recent alluvium of the Cane River flood plain, little additional soft water can be obtained from wells within the city limits.

After a severe water shortage during the very dry summer and fall of 1943, the City of Natchitoches decided to undertake a ground-water exploration program in the area south and east of the city before giving further consideration to a proposal to impound surface water in the near-by swamp known as Sibley Lake. This exploratory program, paid for entirely by the City of Natchitoches but directed by the Ground Water Division, in coöperation with the Louisiana Geological Survey, consisted of the drilling, electric logging, and testing of nine test holes. These test holes were located principally south and east of the city as shown in Figure 1, wells 20–28. Samples of the sands and water contained therein were collected and analyzed in the laboratory. The water level, temperature, yield,

[1] Manuscript received, October 19, 1944. Published by permission of the director of the Geological Survey.

[2] Associate geologist, Geological Survey, United States Department of the Interior.

[3] Assistant geologist, Geological Survey, United States Department of the Interior.

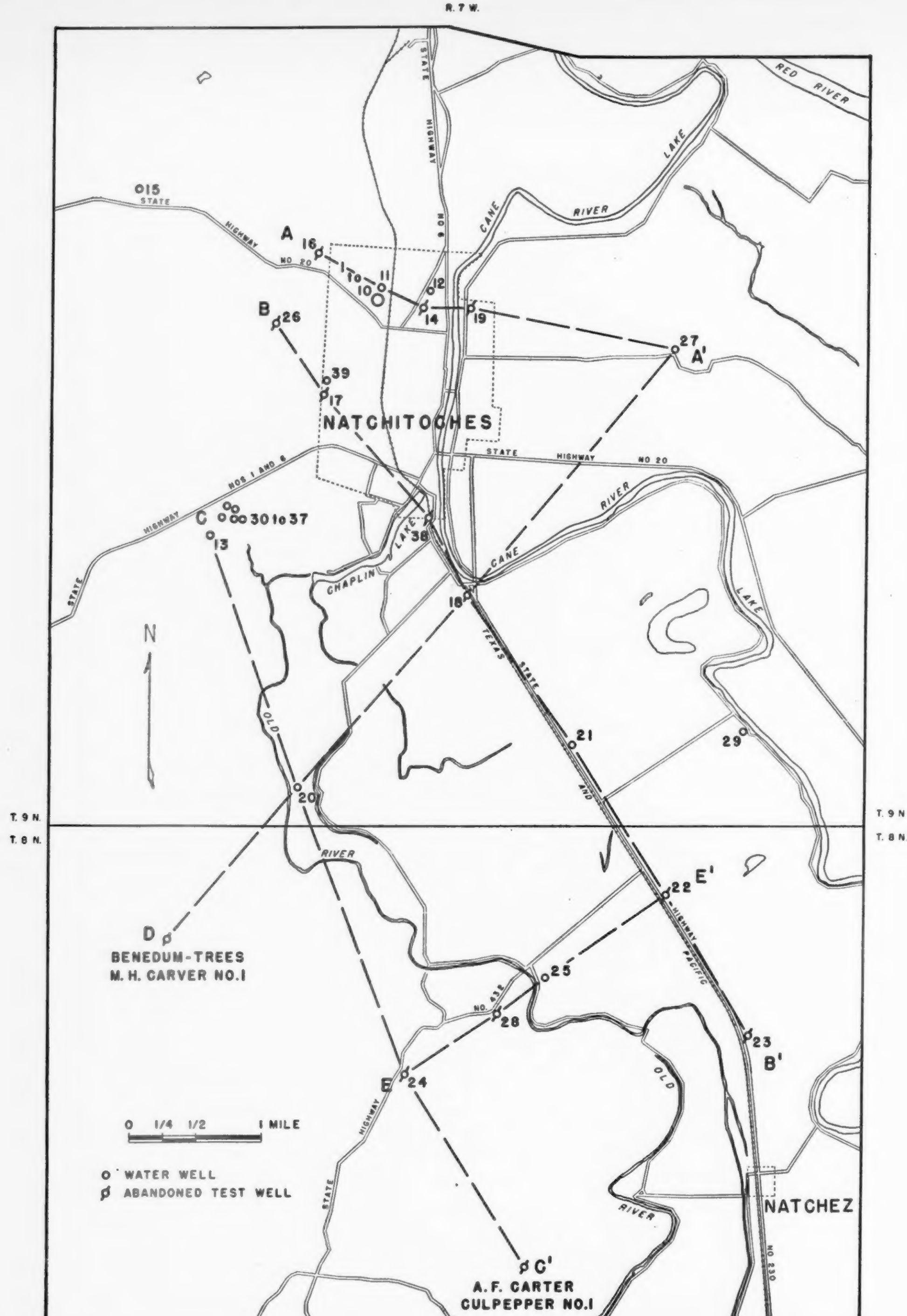


FIG. 1.—Map showing locations of wells in Natchitoches area, Louisiana.

and drawdown were determined for each sand that appeared to have possibilities as an aquifer. This article summarizes and interprets the information obtained during the testing program along with that from records of previously drilled wells.

Acknowledgment is made of the aid and coöperation of Mayor Edwin McClung, C. H. Pierson, A. F. Ortmeyer, and S. L. Perry of the City of Natchitoches. L. P. Blevins, well contractor, gave wholehearted coöperation in obtaining necessary data, and R. T. Wade, Schlumberger Well Surveying Corporation, offered helpful suggestions in the interpretation of the electric logs. The writers are indebted to O. E. Meinzer and V. T. Stringfield of the United States Geological Survey for reviewing this report.

GENERAL GEOLOGY

The city of Natchitoches is located along the western edge of the Red River Valley on the banks of Cane River Lake, a relict meander of the Red River. The Red River Valley, extending diagonally across Natchitoches Parish from northwest to southeast, has been cut into the Tertiary highlands by the Red River and partially filled with alluvium. The Tertiary formations exposed on the bluffs and underlying the flood plain are thick deposits of shallow marine, littoral, deltaic, and continental sediments of Eocene age about which only meager data are available for this locality. Considerable information of the paleontology and regional correlations of these Eocene formations has been published by Harris,[4] Veatch,[5] Spooner,[6] Moody,[7] Howe,[8] Ellisor,[9] Huner,[10] Barry and LeBlanc,[11] and others, but no areal geologic maps or detailed subsurface studies of the area between Natchitoches and Natchez (Louisiana) (Fig. 1) have been printed.

The Eocene formations contain numerous very fine to medium-coarse water sands which exhibit the extremely irregular character, thickness, and lateral extent of continental deposits. The relatively thin-bedded sands of the Wilcox

[4] G. D. Harris, "A Preliminary Report on the Geology of Louisiana," *Geol. Survey of Louisiana Rept. for 1899* (1899), pp. 141–48.

[5] A. C. Veatch, "Geology and Underground Water Resources of Northern Louisiana and Southern Arkansas," *U. S. Geol. Survey Prof. Paper 46* (1906).

[6] W. C. Spooner, "Interior Salt Domes of Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 3 (1926), pp. 217–92.

[7] A. C. Ellisor, "Correlation of the Claiborne of East Texas with the Claiborne of Louisiana," *ibid.*, Vol. 13, No. 10 (1929), pp. 1335–46.

[8] C. L. Moody, "Tertiary History of Region of Sabine Uplift, Louisiana," *ibid.*, Vol. 15, No. 5 (1931), pp. 531–51.

[9] H. V. Howe, "Review of Tertiary Stratigraphy of Louisiana," *ibid.*, Vol. 17, No. 6 (1933), pp. 613–55.

[10] J. Huner, Jr., "Geology of Caldwell and Winn Parishes," *Louisiana Dept. Conserv. Geol. Bull. 15* (1939).

[11] J. O. Barry and R. J. LeBlanc, "Lower Eocene Faunal Units of Louisiana," *ibid.*, *Bull. 23* (1942).

formation[12] and the massive sands of the Sparta sand are the most important aquifers. South of Natchez (Louisiana) the sands in the Cockfield formation are well developed and water-bearing, but only a partial section of the Cockfield formation is present within the area under consideration. The sands of both the Wilcox and Sparta are overlain and underlain by impermeable beds, and yield water under artesian conditions except in their respective outcrop areas. From the northwestern part of the city of Natchitoches southward, successively younger rocks crop out in the hill land or underlie the flood plain in the following manner: Wilcox formation, Claiborne group - Cane River formation, Sparta sand, Cook Mountain formation, and Cockfield formation. In the Red River Valley the bevelled outcrops of these formations are buried beneath alluvium ranging from a few feet to 104 feet in thickness. The possible presence of thin remnants of Pleistocene terraces on the Eocene formations at Natchitoches has not been investigated in this study. Table I gives a generalized description of the geological formations and their water-bearing properties.

STRUCTURAL GEOLOGY

The Natchitoches area is structurally situated on a regional monoclinal flexure described by Veatch[13] in 1906 as extending from Angelina County, Texas, through Louisiana north of Natchitoches, Winnfield, and Columbia to Mississippi River north of Vicksburg. This regional structure developed in Tertiary time along a line of weakness which almost parallels the outcrop of the Wilcox formation west of Red River. H. V. Howe[14] has summarized the effect of this monocline on the accumulation of petroleum as follows.

> The Angelina-Caldwell flexure separates northern Louisiana, with its numerous Cretaceous fields, from central and southern Louisiana in which areas the oil production is of Tertiary age. North of this "flexure" Cretaceous formations lie at relatively shallow depths and are gently folded into the broad Sabine Uplift on the west and Monroe Uplift on the east. On each uplift are smaller, sharper folds which have served for the localization of oil and gas deposits. The depressed area between the major uplifts contains the salt domes of north Louisiana as well as a number of other structures on which salt has not been encountered.
>
> Southward from the Angelina-Caldwell flexure, in that portion of Louisiana west of the Mississippi River, the regional dip of the Tertiary formations is to the southeast at a rate of from 100 feet per mile to probably more than 200 feet per mile, and the Cretaceous formations are depressed under the thick accumulation of Eocene and younger sediments. The position of the Angelina-Caldwell flexure appears to coincide remarkably with the position of the Sabine (Wilcox) shoreline.

This regional monocline is complicated in the Natchitoches area by several

[12] The term "Wilcox formation" is used by the United States Geological Survey; the name "Sabine group" is preferred by the Louisiana Geological Survey.

[13] A. C. Veatch, *op. cit.* (1906), p. 315.

[14] H. V. Howe, "Louisiana Petroleum Stratigraphy," *Louisiana Dept. Conserv. Gen. Min. Bull.* 27 (1936), pp. 19, 20.

TABLE I

OUTLINE OF STRATIGRAPHY IN NATCHITOCHES AREA, LOUISIANA

System	*Series*	*Formation*		*Approx. Total Thickness (Feet)*[1]	*Character of Rocks*	*Water-Bearing Properties*
Quaternary	Recent			0–104	Silt, clay, sand, and gravel confined to stream valleys	Yields moderate quantities of hard water containing considerable amount of iron
	Pleistocene			?	Clay, sand, and gravel as terraces along stream valleys	Too thin to be source of water in this area
Tertiary	Eocene	Claiborne group	Cockfield formation	(500?)[2]	Massive irregular light-colored sands with thin-bedded sandy clays and lignitic clays without marine fossils	Yields small to moderate quantities of soft water
			Cook Mountain formation	224–244	Vari-colored glauconitic and carbonaceous clays, cross-bedded ferruginous sands, fossiliferous marl, and ironstone	Relatively impermeable, with little or no fresh water
			Sparta sand	260–283	Massive irregular sands with interbedded sandy clay	Test wells indicate moderate to large supplies of soft water may be obtained from this formation where sandy phases are well developed
			Cane River formation	106–135	Chocolate-brown clays, glauconitic marl, and sandy shales with marine fossils	Relatively impermeable with no fresh water
		Wilcox formation		(2,500?)[3]	Dark finely laminated sands and clays with considerable lignite	The sands in upper 200 feet yield small to moderate quantities of soft fresh water. Permeability is generally low

[1] Total thickness of complete section in wells in this area.
[2] Cockfield formation reported to exceed 500 feet in thickness.
[3] The Wilcox formation, including the lower section now assigned to Midway group by Louisiana Geological Survey, is reported to approximate 2,500 feet in thickness.

faults and an abrupt change in the direction of the regional strike from northeast to almost due north. These local structural conditions are illustrated in Figure 2, a structural map of the area in which subsurface control was adequate to contour the top of the Wilcox formation, and Figures 3–7, geological cross sections along the lines indicated in Figure 1. Three major faults, one near Natchez and two near Natchitoches, are suggested by abrupt changes in formational dip, abnormal artesian conditions, and the anomalous presence of salt water in fresh-water

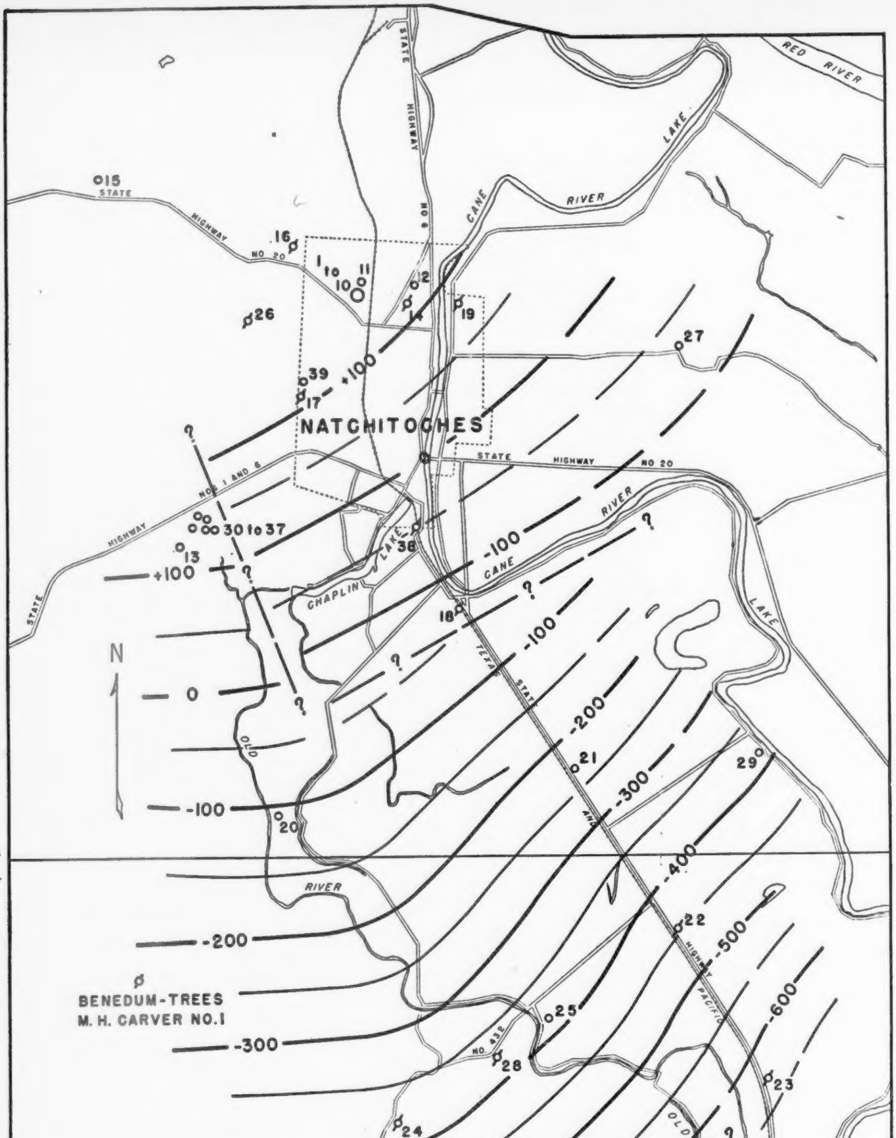


FIG. 2.—Structural map of Natchitoches area contoured on top of Wilcox formation.

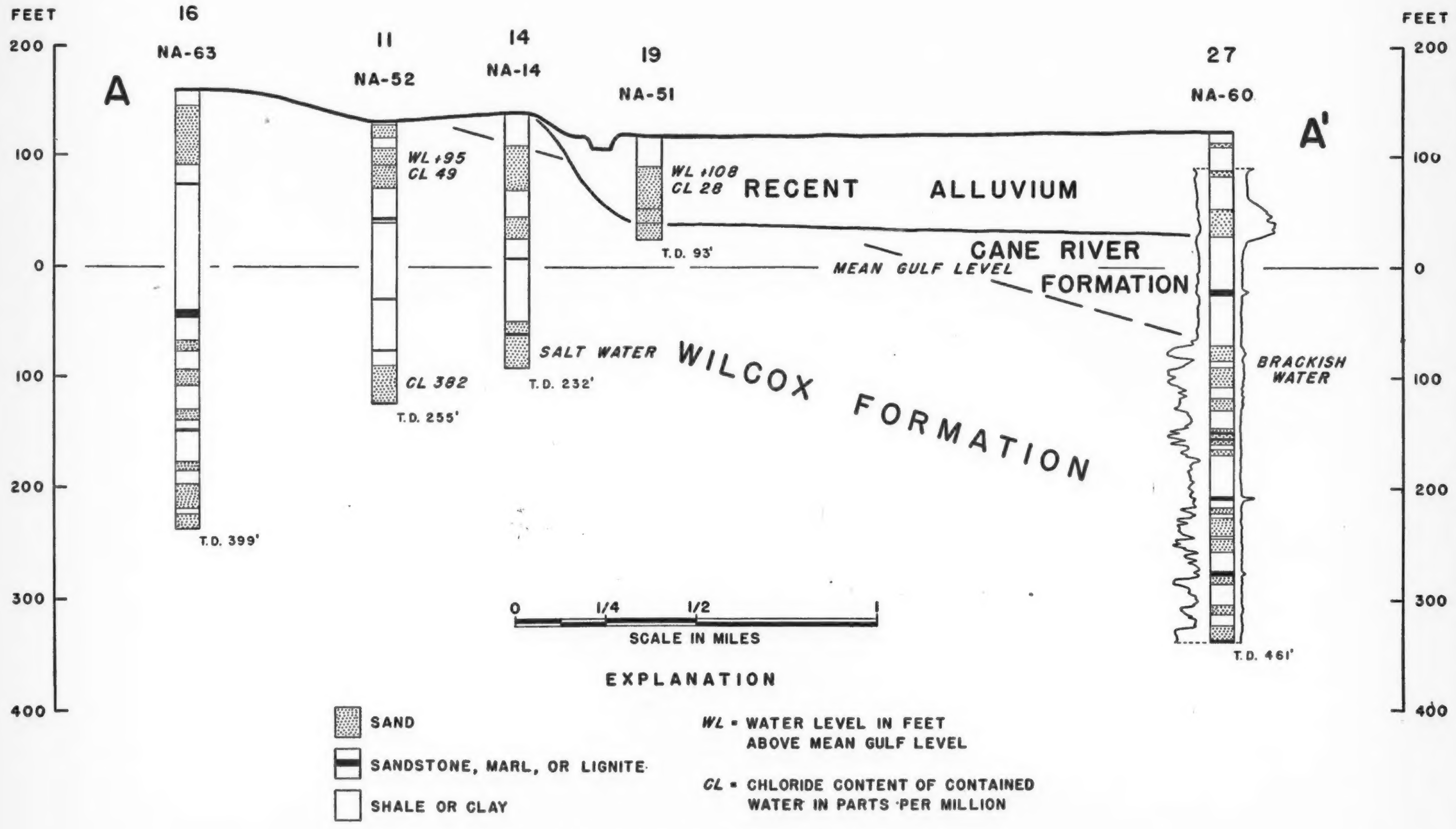


FIG. 3.—Geologic cross section along line AA' as shown in Figure 1.

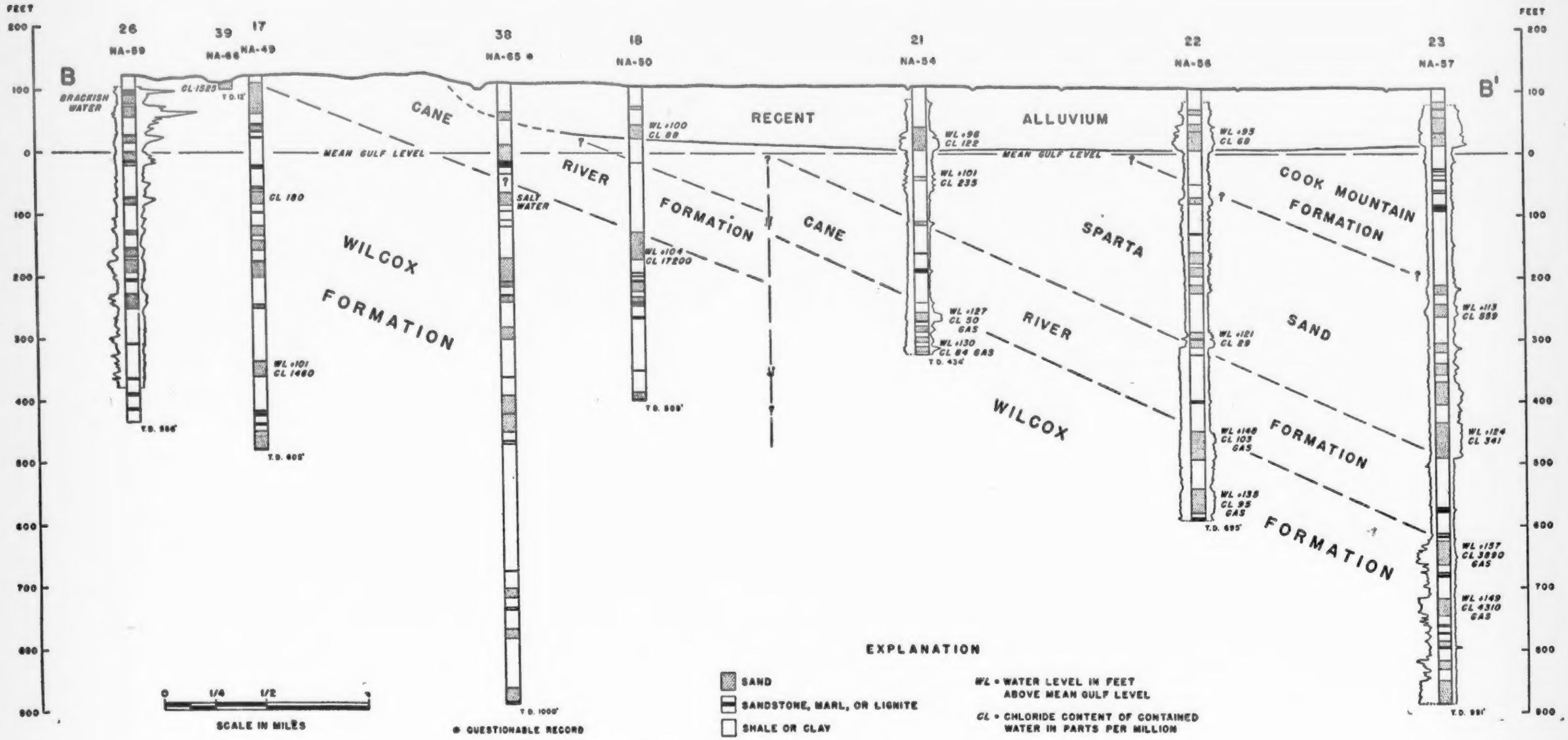


FIG. 4.—Geologic cross section along line BB' as shown in Figure 1.

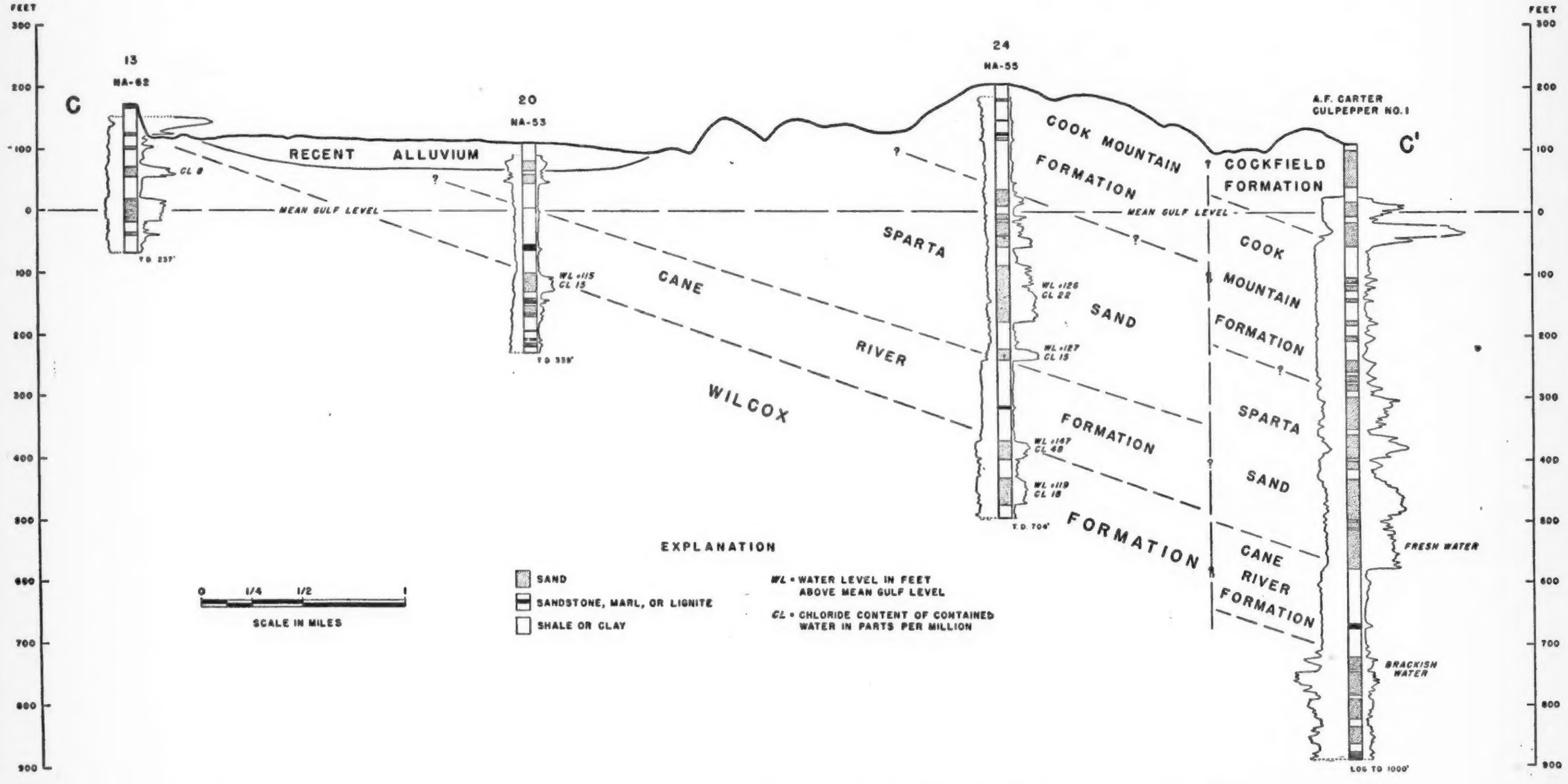


FIG. 5.—Geologic cross section along line CC' as shown in Figure 1.

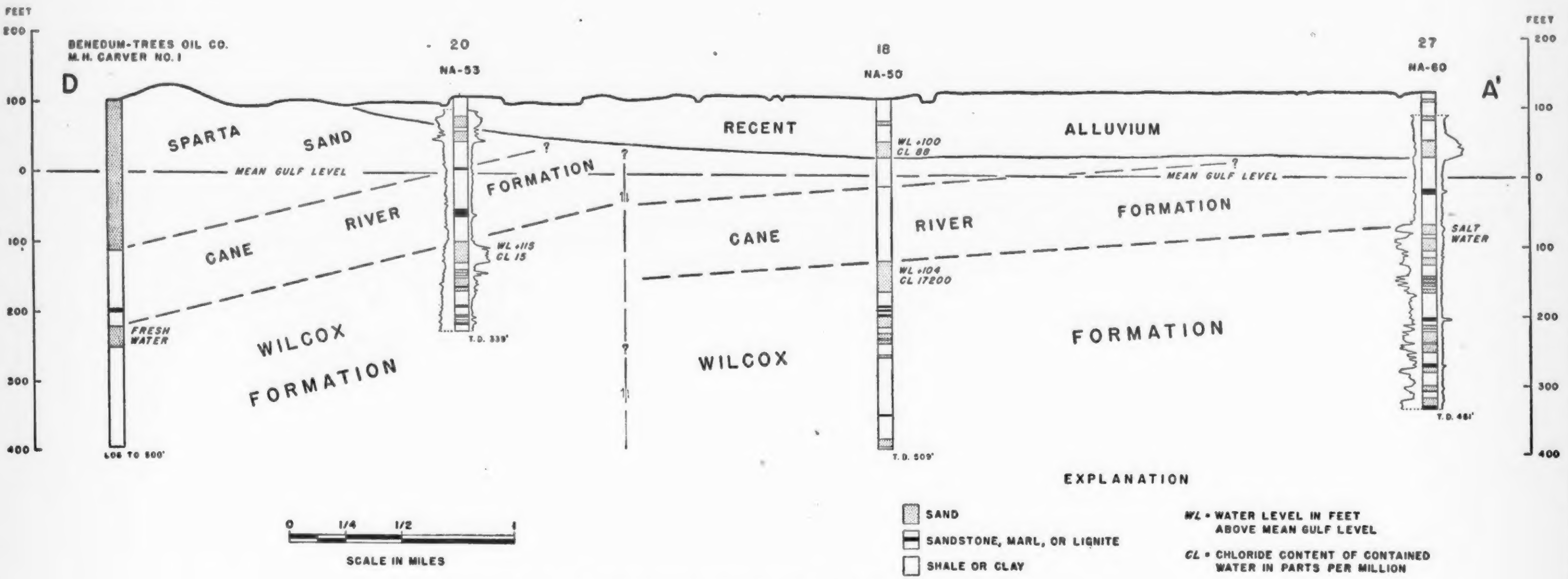


FIG. 6.—Geologic cross section along line DA' as shown in Figure 1.

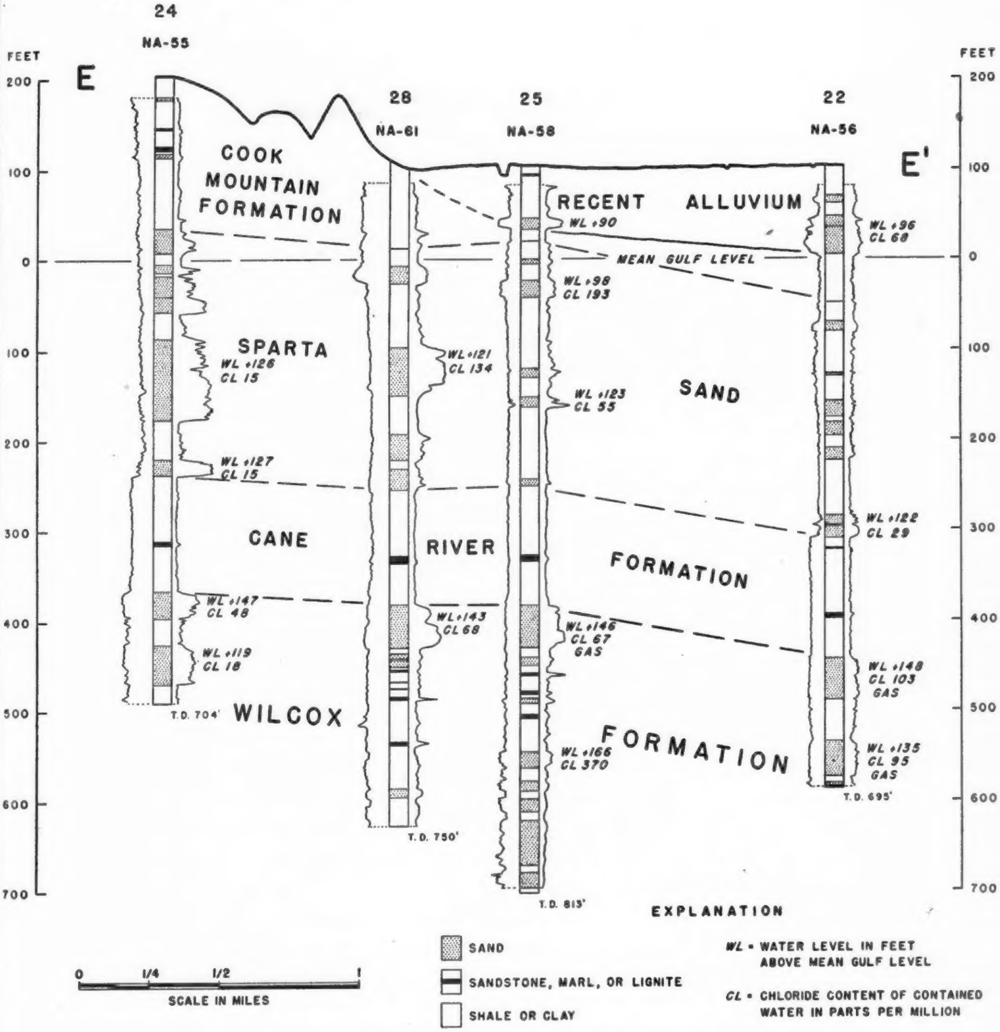


FIG. 7.—Geologic cross section along line EE' as shown in Figure 1.

sands. Vertical displacements of 75–100 feet appear to have occurred along each of the faults, giving rise to topographic irregularities wherever the faults are not buried beneath the floodplain alluvium.

The fault near Natchez trends northeasterly between well 24 (Sec. 56, T. 8 N., R. 7 W.) and the A. F. Carter's Culpepper oil test No. 1 (Sec. $36\frac{1}{2}$, T. 8 N., R. 7 W.) as shown in Figure 2. The apparent dip of the Wilcox formation between well 24 and Culpepper No. 1 is about 220 feet per mile, which indicates a structural break in the intervening area when compared with the lesser dip of 120 feet per mile between wells 13, 20, and 24 (Fig. 5). As further evidence of this break, the upper sands of the Wilcox in Culpepper No. 1 contain brackish to salty water, whereas the same sands in wells 13, 20, and 24 contain fresh water. The formations on the southeast side of this fault are about 100 feet lower structurally than those on the northwest side. The strike of the fault can not be accurately ascertained from the data available, but the abrupt termination of Big Henry Branch in the swamp area in Secs. $34\frac{1}{2}$ and $35\frac{1}{2}$, T. 8 N., R. 7 W., suggests the direction indicated in Figure 2.

Two faults near Natchitoches lie at right angles to each other and probably intersect about two miles southwest of the city in the vicinity of Old River. One of them trends southeastward from Sibley Lake along Youngs Bayou, passing into a slight structural nose 1 or 2 miles south of State Highways 1 and 6 (Figs. 2 and 7). The maximum vertical displacement of this fault is about 100 feet, forming a scarp west to Youngs Bayou. The water in the upper sands of the Wilcox on the west is fresh; that on the east is salty. The other fault extends northeastward from its probable intersection with the Youngs Bayou fault at least as far as Cane River Lake. This structural break, shown in Figures 4 and 6, has a vertical displacement of about 75 feet with the downthrown side on the northwest. Salt water is present in the upper sands of the Wilcox on the downthrown side. This fault is obscured by floodplain alluvium, but may be reflected in the abnormal drainage pattern south of Chaplin Lake (Fig. 1). It is interesting to note the effect of this fault or barrier upon the artesian pressure gradient which normally decreases away from the outcrop. The water level of the first sand of the Wilcox in well 18, on the north (downthrown) side, was about 104 feet above mean gulf level, while the water levels in wells 21, 22, and 23 on the south side of the fault were 127, 148, and 157 feet above mean gulf level, respectively. This shows an increase away from the nearest outcrop of the sand and implies that recharge is obtained laterally from the west. Small amounts of natural gas found in the fresh water south of the fault may account for part of the higher artesian pressures, but the relative isolation of the salt water updip from the fresh water supports the idea of normal artesian conditions modified by a fault barrier.

The relative positions of the two faults suggest that the city of Natchitoches and the Louisiana State Normal College may be situated on a downthrown fault block defined on the southwest by the fault along Youngs Bayou and on the southeast by the fault extending from Old River toward Cane River Lake. Un-

fortunately the lack of adequate well records prevents the definition of the northeast and northwest limits of this block, but the widening of the contours between wells 14 and 19 on the structural map (Fig. 2), and the presence of brackish water in the upper sands of the Wilcox in well 19 may be significant. If credence can be given the drillers' logs reported for wells 1, 11, 14, and 16, which were drilled from 3–30 years ago, some flattening of the formational dip at the city well field may be inferred. Necessary subsurface control farther northwest has been lost through the failure to preserve a log of formations penetrated in the salt-water well at the Country Club (well 15). In a road cut near this well, steep dips toward the southeast were noted in the sandy shales of the Wilcox formation. Considerably more data and detailed work are needed properly to outline this structure.

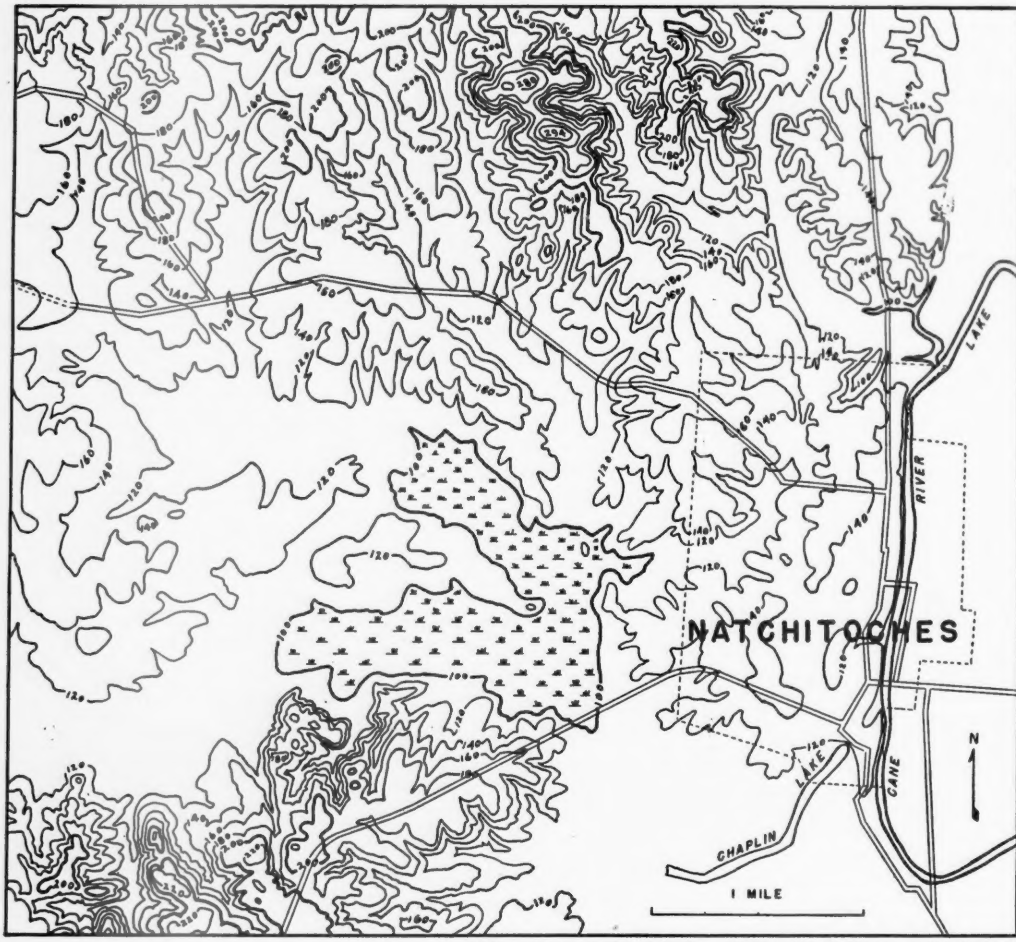
The upper sands of the Wilcox in this downthrown block contain brackish or salt water except in or near the recharge area where fresh water enters the outcrops. The shallow wells at relatively higher elevations in the northwestern part of the city are the only fresh-water wells on the fault block. Brine has been reported in the sands of the Wilcox penetrated by well 38 at the Natchitoches Oil Mill and other wells drilled on or near the Louisiana State Normal College campus during the past 45 years. The uppermost sand in the Wilcox in well 18, near the Cane River bridge south of the city on State Highway 230, yielded water that contained 17,200 parts per million of chloride. The Louisiana State Normal College wells, about one mile west of the campus, and wells 20, 21, 22, 24, 25, 28, and 29, 1–5 miles south of Natchitoches, are located beyond the faults limiting the west and south sides of the downthrown block, and consequently yield fresh water.

The origin of this fault block may be associated with the origin of the topographic feature west of the city known as Sibley Lake. This so-called lake is in reality a swamp drained only by Youngs Bayou to the south, along which a fault is indicated. This swamp is almost completely circled by hills (Fig. 8), receiving run-off from the upper end of Youngs Bayou on the west, Rio Hondo on the northwest, several unnamed streams on the north, and Bayou Jacko on the east. As shown in Figure 8, a sketch map of the topography of this area, the surface of the swamp is less than 100 feet above mean gulf level. This indicates that subsidence, similar to the central collapse over salt domes described by Spooner,[15] may be responsible for both Sibley Lake and the downthrown fault block at Natchitoches. The presence of a salt dome in this area can not be proved from the available data, but the fact that the salt water from the first sand of the Wilcox in well 18 is not similar in chemical composition to connate sea water but resembles a soft sodium-bicarbonate water mixed with salt-dome brine[16] lends support to the theory. Veatch[17] in 1906 expressed the belief that subsurface leakage of brine

[15] W. C. Spooner, *op. cit.*, pp. 223–24.

[16] M. D. Foster, personal communication.

[17] A. C. Veatch, *op. cit.*, p. 78.



FROM U.S.G.S. FIELD SHEETS, CAMPTI AND BERMUDA QUADRANGLES

FIG. 8.—Sketch map showing topography at Natchitoches, Louisiana.

from known salt domes far on the north had contaminated the ground water at Natchitoches. In view of the new data at hand, this long-distance migration of brine seems very doubtful. Wells dug 12–16 feet deep into the outcrop of the uppermost sand of the Wilcox in the Bayou Jacko lowlands west of the city are known to yield brackish or salty water (well 39). Geophysical investigations by commercial operators may already have proved or disproved the existence of a salt-dome structure at Natchitoches, but the results of such investigations have not been available to the writers.

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING PROPERTIES

In the following discussion, beginning with the Wilcox formation, the geological formations underlying this area are listed in the order in which they were deposited and in which they crop out from north to south. The results of chemical analyses of 39 samples of water from 9 wells and 10 test holes are summarized under the respective formations. These analyses were made in the water resources laboratories of the United States Geological Survey by M. D. Foster, L. W. Miller, W. W. Hastings, and J. H. Rowley. Complete tables of chemical analyses, mechanical analyses, well logs, and records are on file at the offices of the Geological Survey in Baton Rouge, Louisiana, and in Washington, D. C.

EOCENE SERIES

Wilcox formation.—The sediments of the Wilcox formation[18] crop out in a relatively wide belt extending from southeastern Sabine Parish northeast to the Red River near Natchitoches and thence northward into Arkansas. These sediments, representing alternating marine and non-marine deposition near the strand line in Wilcox time, are composed principally of dark finely laminated micaceous sands and clays of irregular character, thickness, and distribution. The sands, which predominate in the section, are generally laminated or cross-bedded; only a few appear on the outcrop to be massive. Most of the sands are fine-grained although coarse-grained phases are present at a few places. The clays and shales range from buff to black in color, and contain considerable lignitic material and some layers of marine shells and glauconite. Concentrations of pyrite nodules large enough to be logged as rock have been found in water wells penetrating the Wilcox sediments, and sandy limestone is not uncommon.

According to Spooner[19] the Wilcox sediments range from 800 feet in thickness in northern Louisiana to more than 2,500 feet in this area. However, in some recent publications[20] the lower part of this section is now considered to be Midway in age. As water wells in the Natchitoches area penetrate only a few hundred feet

[18] Referred to as Sabine group by the Louisiana Geological Survey.

[19] W. C. Spooner, *op. cit.*, p. 234.

[20] R. J. LeBlanc and J. O. Barry, "Fossiliferous Localities of Midway Group in Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25 (1941), pp. 734–37.
G. E. Murray, "Midway Microfauna of Northwestern Louisiana," *ibid.*, pp. 738–41.

of Wilcox sediments the discussion of this problem is not pertinent in this report.

Fresh water is found at Natchitoches in three sands in the upper 200 feet of the Wilcox formation. These sands are irregular in character and thickness, grading partially into sandy shale and shale at some locations. The upper sand marks the transition from the arenaceous continental deposits of the Wilcox formation to the marine clay and marl of the Cane River formation of the Claiborne group. Unconformable relations reported to exist between the Wilcox and Claiborne were not apparent in this area. The upper sand crops out north and west of Natchitoches, forming gray sandy soil. Numerous exposures are present along State Highway 6 west of Hagewood, and a particularly good exposure is present in a road cut about ½ mile south of Hagewood on State Highway 39. In general the sand is fine to medium-coarse in texture with considerable cross-bedding and many included clay pebbles. It is almost always micaceous, and the basal part generally contains large amounts of glauconite and shell fragments. In water wells and test holes the thickness of the upper sand ranged from 26 to 50 feet, the maximum thickness being in well 17 where the sand lies near the land surface. In other wells the average thickness is about 40 feet. Some of the differences in thickness from well to well are caused by the upper part of the sand lensing into sandy clay or shale, as in well 21 (Fig. 5). Mechanical analyses show that this sand is the coarsest sand of the Wilcox and the geologic cross sections indicate that it is the most uniform in thickness.

The second sand of the Wilcox formation is very irregular in character and contains many hard rock layers and clay lenses. Its thickness ranges from 9 to 45 feet, increasing downdip. The texture of this sand is fine and the permeability is low. In most places 20–40 feet of clay and rock separate it from the upper sand of the formation.

The third sand of the Wilcox appears about 30 feet below the second, and its thickness, which is even more irregular than that of the second sand, ranges from only a few feet to 37 feet. Downdip it grades into fine sand with intercalated clay and layers of rock. This sand is relatively unimportant as an aquifer in the Natchitoches area.

The sands of the Wilcox formation are so fine-grained near the outcrop that most wells so located must be screened in two sands to produce small to moderate quantities of water. Wells 1–12 at the city water plant in northwestern Natchitoches draw upon the first and second sands, yielding an average of 30 gallons a minute per well. Salt water is found below the second sand. The wells are closely spaced and the sands are fine, resulting in overpumping in that area. At the Louisiana State Normal College well field, wells 30–37 are screened in the second and third sands which are better developed at this locality. Here, too, close spacing combined with the fine texture of the sands has caused some difficulty. The yields of these wells are not accurately known but are about the same as those of the city wells. The college wells are situated west of a fault extending

southeastward along Youngs Bayou. This probably accounts for the presence of salt water in the same sands only a mile or so east, at the college proper.

Test holes drilled into the sands of the Wilcox formation where they underlie the flood plain show that these sands have sufficient pressure to flow at the surface at all locations south of well 18. Well 18, apparently located on the downthrown side of a fault (Fig. 4), has an abnormally low water level of 104 feet above mean gulf level (8 feet below the land surface). The remainder of the tests in the flood plain recorded water levels in the sands of the Wilcox ranging from 115 to 157 feet above mean gulf level ($4\frac{1}{2}$–58 feet above the land surface). Quantities of gas present in some of the tests may be partly responsible for some of the higher artesian pressures recorded. The yields of the test wells ranged from 5 gallons a minute, in well 20, to 30 gallons a minute in well 25. However, 30 feet of screen was set in well 25 as compared with only 10 feet in the others.

Salt water was recorded in the sands of the Wilcox formation in wells 18, 26, 27, 38, and A. F. Carter's Culpepper No. 1. The salt water in wells 18 and 38 is probably a result of contamination by salt-dome brine. This contamination is probably related to two faults (Figs. 4 and 6), one trending northeast-southwest between wells 18 and 21, and the other northwest-southeast, separating the college well field from wells 18 and 38. A sample from well 18 showed 17,200 parts per million of chloride and, according to M. D. Foster of the Water Recourses Branch laboratory, resembled a soft sodium-bicarbonate water mixed with brine from a salt dome. The salt water recorded in the Culpepper oil test is also associated with faulting (Fig. 5). Where geological conditions are normal and the waters fresh, both the hardness and the chloride content of the waters range from about 5 to 100 parts per million. The waters contain variable amounts of iron, these amounts ranging from 0.05 to 12 parts per million. The bicarbonate content ordinarily exceeds 400 parts per million.

CLAIBORNE GROUP. *Cane River formation.*—The Cane River formation, the basal marine formation of the Claiborne group which directly overlies the Wilcox formation, is named for the excellent exposures of marine clays and marls along the west bank of Cane River Lake at Natchitoches. Its outcrop parallels that of the sandy Wilcox formation to the west and north, forming flat-land topography in contrast to the irregular hills of the Wilcox and Sparta. The upper part of the Cane River formation is composed principally of dark glauconitic sandy clay and shale with plentiful microfossils. The lower part consists of fossiliferous glauconitic sandy shale and marl. A soft limestone about 6 feet thick occurs about 40 feet above the base of the formation. This 6-foot limestone bed is a key marker as it is easily identified on the electric logs and drillers' logs. In the Natchitoches area the Cane River formation ranges from 106 feet to 135 feet in thickness, thickening down the dip as shown in Figures 4 and 5. In this area there are no productive water-bearing sands in the Cane River formation, and the little water that does occur in the sandy shales is highly mineralized.

CLAIBORNE GROUP. *Sparta sand.*—Beds of light-colored sand and sandy clay with some lignitic material and only a very few scattered fossils overlie the Cane River formation. These beds are known collectively as the Sparta sand, which was recognized by Spooner[21] as extending downward from the lowest fossiliferous horizon of the Cook Mountain formation to the marine clays of the Cane River formation. Spooner's description of the Sparta sand as given in the following paragraph applies very well to the formation in the Natchitoches area except that the thickness here does not exceed 300 feet.

> The lower half of the Sparta sand is made up chiefly of massive sand with interbedded subordinate members of laminated sandy clay. The massive sands are made up of quartz grains somewhat coarser than found in the Wilcox formation. The upper half contains a relatively greater amount of clay than the lower half. Massive sands alternate with beds of finely laminated sandy clay, in part lignitic and in many places containing fossil leaves. The upper 50 feet of beds contain a considerable amount of lignitic material and some thin lignitic beds which are particularly well exposed in the vicinity of the town of Bienville. The beds are commonly light colored, but, depending upon the amount of iron and carbonaceous matter, red and brown-colored beds occur. Fossils are generally absent from the Sparta sand, but a few species of near-shore forms are found near the middle of the formation. The Sparta sand has a thickness of 400–500 feet, with the greater thickness in the northern part of the salt-dome region.

Massive sands of the Sparta crop out south and southwest of the city of Natchitoches, and form the belt of sandy hills which lies south and southwest of Bayou Souris. The northeast trend of these sandy ridges is interrupted by the Red River Valley where the Sparta sand is buried beneath Recent alluvium.

Previous to the test-drilling by the City of Natchitoches, the Sparta sand had never been developed in any water wells in this vicinity. This is surprising in view of the poor quality of the water from the Recent alluvium in which many farm wells have been finished, and the relatively shallow depth to the Sparta sand in most of the area. Seven of the nine test wells drilled by the City tested the Sparta sand, five of them (wells 22, 23, 24, 25, and 28) penetrating complete sections of the Sparta. One other well, and oil test (A. F. Carter's Culpepper No. 1, Sec. 36½, T. 8 N., R. 7 W.), also drilled through a complete section of the formation. On the basis of these wells, the total thickness of the Sparta sand ranges from 260 feet to 283 feet, thickening downdip toward the south. The percentage of sand in the section also increases downdip, being less than 20 per cent in well 25 and more than 80 per cent in A. F. Carter's Culpepper No. 1. The sands are generally fine to medium-coarse, the finer material predominating. Despite the irregular and unpredictable character of the sand bodies, the principal water sands are probably interconnected as the water levels recorded in drill-stem tests at different sand horizons in the Sparta agree very well. Drill-stem tests of the Sparta sand were made in six of the test holes. The water levels ranged from 101 feet above mean gulf level (8 feet below the land surface), in well 21, to 127 feet above mean gulf level (80 feet below the land surface) in well 24. Intermediate

[21] W. C. Spooner, *op. cit.* (1926), p. 236.

artesian heads are present between these wells, showing a pressure gradient eastward. This is in accord with geologic evidence pointing to recharge of the water sands in the hill lands west of the flood plain. The yields obtained in the drill-stem tests ranged from 5 to 48 gallons a minute, the highest yield being from well 24. These yields are valuable only for comparative purposes and do not represent the probable yields of supply wells in the formation tested. Fresh water was found in all of the drill-stem tests except those in well 23, the southeasternmost test well. The water from this well was slightly brackish; the sample from the upper Sparta sand tested 559 parts per million of chloride and the one from the lower Sparta sand, 341 parts per million. This limits the area in which fresh water may be found in the Sparta sand beneath the flood plain to the land south of wells 20 and 21, and northwest of well 23. In the hill land, the Sparta sands contain fresh water as far south as Flora.

The fresh water from the Sparta sand is generally soft and alkaline. In the nine samples analyzed, the hardness ranged from 4 to 114 parts per million and averaged 33.5 parts per million. The maximum figure, 114 parts per million, was recorded for a sample from well 21, where the bevelled edge of the Sparta sand is directly overlain by Recent alluvium containing hard water. It is thought that the sample of water from Sparta sand in well 21 was a mixture of waters from the Sparta sand and the Recent alluvium. This conclusion is borne out by the relatively large iron content (1.1 parts per million) of the sample. The bicarbonate content of the samples averaged 317 parts per million. None of the samples contained fluoride in excess of one part per million.

Claiborne group. *Cook Mountain formation.*—The Cook Mountain formation is composed of fossiliferous marine sands and clays lying between the non-marine sandy sediments of the Cockfield formation and Sparta sand. The sands are generally fine-grained and very irregular in character, usually containing numerous hard layers of ferruginous sandstone. The color of the sands ranges from light gray to brown and red. The clays are of many different colors, depending upon the amounts of iron, carbonaceous material, and glauconite present. Nodular limestone horizons and marl beds occur in the lower part of the formation, and both the uppermost and lowermost beds are extremely fossiliferous. The thickness of the formation in the Natchitoches area ranges from 224 to 244 feet. Due to its relative impermeability, this formation can not be considered as a possible source of water supply at Natchitoches.

In the course of the field work in the outcrop area of the Cook Mountain formation south of Natchitoches, an interesting vertebrate fossil was found by the junior author in the lower part of the section (Huner's[22] Milams member of the Cook Mountain formation) which is exposed at the edge of the hills adjacent to the flood plain in Sec. 10, T. 8 N., R. 7 W. (about 100 feet north of well 28). The fossil material was collected and sent to J. B. Reeside, Jr., of the United States

[22] J. Huner, Jr., "Geology of Caldwell and Winn Parishes," *Louisiana Dept. Conserv. Geol. Bull.* *15* (1939), pp. 91–95.

Geological Survey in Washington, D. C., who referred the material to Remington Kellogg of the United States National Museum. The following is a quotation from a letter from Reeside regarding the identity of the specimen.

> Remington Kellogg, of the U. S. National Museum, reports that the specimen from the Cook Mountain formation in Natchitoches Parish is an entirely new Archaeocete (the toothed whales formerly known as Zeuglodonts). It still lacks a name and, being new, gives little help in correlation. The occurrence is the earliest recorded for this group of animals in the Gulf region.

H. V. Howe, of Louisiana State University, identified the following list of microfossils from the clay matrix of the specimen, and confirmed the field identification of the matrix as marl from the Milams member of the Cook Mountain formation.

FORAMINIFERA

Siphonina claibornensis
Siphonina goochi
Siphoninella claibornensis
Gyroidina soldanii octocamerata
Eponides guayabalensis
Anomalina costiana
Anomalina umbonata
Ceratobulimina eximia
Planulina kniffeni
Cibicides pseudowuellerstorfi
Cibicides lawi
Cibicides sassei
Cibicides mauricensis
Asterigerina hadleyi
Globorotalia centralis
Globorotalia crassata
Globorotalia spinulosa
Globigerina topilensis
Globigerina ouachitaensis
Globogerina mexicana
Textularia zapotensis
Karreriella mauricensis
Robulus alate-limbatus
Robulus pseudocultratus
Robulus jugosus
Lagena mauricensis
Lagena ouachitaensis
Guttulina austriaca
Guttulina irregularis
Globulina minuta
Globulina gibba
Nonion florienensis
Nonion planatum
Nonion micrum
Nonionella mauricensis
Discocyclina perpusilla
Triloculina garretti
Triloculina trigonula
Triloculina mindenensis
Triloculina natchitochensis
Uvigerina blanca-costata
Loxostomum claibornense
Bulimina robertsi
Quinqueloculina mauricensis
Massilina mauricensis
Operculinoides sabinensis
Cornuspira olygogyra
Glandulina laevigata
Kobulus mexicanus
Dentalina winniana
Discorbis ? globulospinosa

OSTRACODA

Cythereis cooleycreekensis
Cythereis winniana
Cythereis undosa
Cytheridea montgomeryensis
Cytheridea oliveri
Cytheropteron proboscense
Loxoconcha claibornensis
Loxoconcha chamfera
Brachycythere russelli
Brachcythere watervalleyensis

CLAIBORNE GROUP. *Cockfield formation.*—The Cockfield formation is exposed at the surface in the southern part of the Natchitoches area west of Natchez. It consists of fine, light-colored, generally massive sands, with laminated, thin-bedded sandy clays and lignitic silty shales. Although no marine fossils are reported in the formation, numerous horizons of fossil leaves and concretionary zones are present. The entire section has not been penetrated by wells in this area, but it is reported to exceed 500 feet in thickness in oil tests in adjacent areas.

The only well included in this report that penetrated the Cockfield is A. F. Carter's Culpepper No. 1, on the downthrown side of a fault (Fig. 2). This oil test drilled through 163 feet of the Cockfield, beginning at the land surface.

The Cockfield formation yields fresh water to wells several miles farther south. At Flora wells ranging from 300 to 350 feet in depth draw upon this source. Because of the low permeability of the water sands, the yields of these wells are not large. The water is reported to be moderately soft to moderately hard (50–120 parts per million) and to contain rather large amounts of bicarbonate and sulphate.

PLEISTOCENE AND RECENT SERIES

Sand, gravel and clay of Pleistocene and Recent age mantle the older formations in central Louisiana. The Pleistocene deposits have been described by Fisk[23] as four formations (Prairie, Montgomery, Bentley, and Williana) which form four terraces above the present Red River flood plain. Huner[24] mapped these terraces in near-by Winn Parish, but similar work has not been done in Natchitoches Parish. Remnants of these terraces may be present in the hills in the area under consideration, but they are too thin and scattered to warrant consideration as aquifers. The flood plain along Cane River Lake is underlain by Recent alluvium ranging in thickness from a few feet to about 104 feet. This alluvium grades downward from clay into coarse sand and gravel. The upper red-colored clay is 25–35 feet thick and overlies bodies of fine sand and sandy clay which extend to a depth of about 50–60 feet. The coarse material is generally below a depth of 60 feet. Gravel is not present at all locations, although the sand is generally coarse enough to yield moderately large supplies of water.

The water level in the Recent alluvium ranges from 9 to 17 feet below the land surface. Yields of 3–25 gallons a minute were obtained in drill-stem tests of this source. The temperature ot the water is about 67°F. All of the water is hard, the hardness ranging from 342 to 510 parts per million, and the iron content ordinarily exceeds 3 parts per million. This water is not suitable for most domestic purposes without treatment.

SUMMARY AND CONCLUSIONS

Geologic and hydrologic data obtained from this exploratory program suggest that the city of Natchitoches may be situated on a downthrown fault block defined on the southwest by a fault along Youngs Bayou and on the southeast by a fault extending from Old River toward Cane River Lake. Salt water, unlike connate sea water in composition, is present in the sands underlying most of the city. A similarity of topographic, geologic, and hydrologic conditions in this area to those in salt-dome areas in near-by parishes is evident.

[23] H. N. Fisk, "Geology of Avoyelles and Rapides Parishes," *Louisiana Dept. Conserv. Bull. 18* (1940), p. 175.

[24] J. Huner, Jr., *op. cit.*, pp. 46–55.

In the area between Natchitoches and Natchez (upper half of T. 8 N., R. 7 W., and all of T. 9 N., R. 7 W.), the geologic formations which will yield moderately large quantities of water are the upper sands of the Wilcox formation, the Sparta sand and the Cockfield formation of the Claiborne group, and the Recent alluvium. The water from the Recent alluvium is not satisfactory for a public supply or for most industrial uses without treatment, as it is very hard and contains objectionable amounts of iron. The water from the Cockfield formation is generally moderately soft to moderately hard in character, and is well suited to domestic or industrial use; but the formation is present only in the extreme southern part of the area.

The upper sands of the Wilcox which underlie Natchitoches supply small amounts of fresh water to municipal wells in the north part of the city and to the wells of the Louisiana State Normal College southwest of the city. Between the two well fields the sands of the Wilcox contain salt water, the occurrence of which is probably associated with structural deformation in the Sibley Lake area. The water-bearing sands have been overdeveloped at both well fields, and it would be inadvisable to drill additional wells at either place. The site for a new well field must, therefore, be south of the city, beyond the areas of faulting and salt-water contamination.

Test wells 20 and 21 revealed that the upper sands of the Wilcox at these locations contain fresh water, but are too thin and fine-grained to warrant the installation of supply wells. The proximity of faulting and the unfavorable location with respect to the area of recharge further impairs their possibilities. Test well 22 recorded sands of the Wilcox of favorable thickness and texture, but the danger of salt-water intrusion renders this location undesirable. The chloride content of waters from the Wilcox in well 22 is 95–103 parts per million, but in well 23, 1¼ miles south, these waters are salty (Fig. 4). Heavy pumpage in the vicinity of well 22 might cause the salt water to encroach upon the pumped wells. The locations of test wells 24, 25, and 28 appear to be satisfactory for supply wells in the Wilcox formation.

The Sparta sand does not underlie Natchitoches and immediate vicinity, but the bevelled edge of the formation was penetrated by both wells 20 and 21, located about 1½ miles south of Natchitoches (Figs. 4 and 5). Water sands of the Sparta tested in wells 20, 21, and 23 are not considered worthy of development because they either contain highly mineralized water or are too thin and fine-grained. West of the valley the sands of the Sparta are thicker and more permeable, the water levels are higher, and the quality of the water is good. Tests 24 and 28 revealed sands in the Sparta that are suitable for development in supply wells.

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MIDWAY-WILCOX SURFACE STRATIGRAPHY OF SABINE UPLIFT, LOUSIANA AND TEXAS[1]

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Jackson, Mississippi, and Shreveport, Louisiana

ABSTRACT

The Sabine uplift of northwestern Louisiana and northeastern Texas is reflected on the surface by a large inlier of Midway, Wilcox, and lower Claiborne sediments. Surface work in this area revealed the presence of three Midway and four Wilcox formations. The formations consist typically of a basal sandy member, a middle lignitic and carbonaceous shale member, and an upper calcareous silt and shale member. The following nomenclature is proposed for these sediments.

- Wilcox group
  - Carrizo formation
  - Sabinetown formation
  - Pendleton formation
    - High Bluff member
    - Slaughter Creek member
    - Bayou Lenann member
  - Marthaville formation
- Midway group
  - Hall Summit formation
    - Bistineau member
    - Grand Bayou member
    - Loggy Bayou member
  - Logansport formation
    - Lime Hill member
    - Cow Bayou member
    - Dolet Hills member
  - Naborton formation (base not exposed)

The Midway and Wilcox beds are largely deltaic and barren of fossils, but marine faunas are present therein around the southern flank of the uplift. These faunas permit correlation with the type Midway and Wilcox sediments of Alabama and Mississippi. The mapping methods employed revealed surface indications of nearly all the known oil and gas fields of the area.

Introduction

The Sabine uplift of northwestern Louisiana and northeastern Texas is reflected as a sub-regional doming by the presence of a large inlier of Midway, Wilcox, and lower Claiborne sediments. The Midway and Wilcox beds are largely deltaic and barren of fossils, but lentils bearing marine faunas are found therein around the southern flank of the uplift. The Wilcox age of the upper part of this section was definitely established at an early date by Harris and Veatch[3] and the entire section was considered to be Wilcox in age by subsequent writers[4] until a

[1] Manuscript received, November 18, 1944.

[2a] Magnolia Petroleum Company.

[2b] Ohio Oil Company.

[3] G. D. Harris, "The Lignitic Stage, Part 2, Scaphopoda, Gastropoda, Pteropoda, and Cephalopoda," *Bull. Amer. Paleon.*, Vol. 2, No. 9 (1897). 103 pp.
———, "The Cretaceous and Lower Eocene Faunas of Louisiana," *Louisiana State Exp. Sta. Geol. Rept. for 1899*, Spec. Rept. 6 (1899), pp. 289–310.
——— and A. C. Veatch, "A Preliminary Report on the Geology of Louisiana," *Louisiana State Exp. Sta. Geol. Rept. for 1899*, Pt. 5, Sec. 2 (1899), pp. 45–138.

[4] C. L. Moody, "Tertiary History of the Region of the Sabine Uplift, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 5 (1931), pp. 531–51.

recent investigation by members of the Louisiana Geological Survey[5] revealed the presence of sparse faunas of Midway age in the lower part.

Three Midway and four Wilcox formations are now recognized within the section exposed on the Sabine uplift and these units are correlated with the type formational units of the Midway-Wilcox section of Alabama as shown in Figure 1. In this report each of these seven formations is discussed lithologically; their geographic distribution is shown on the geologic map (Fig. 2). Partial faunas are listed and their significance is discussed. The cyclic depositional pattern, which is the basis on which this deltaic complex has been subdivided into formational units, is discussed in some detail along with the applications and limitations of the method. Hitherto unsuspected reflections of local structure are indicated in Figure 3.

The results and conclusions herein presented are based on approximately 6 months of field work by the senior writer and other members of the Louisiana Geological Survey staff in 1939 and 1940, and on approximately 8 months of independent work by the junior writer in the East Texas and extreme northwestern Louisiana area for the Ohio Oil Company during 1941 and 1942. Practically all of the Sabine uplift area was covered either in detail or in reconnaissance by these combined efforts. The terminology used in this report is compiled from several sources, some old and some new. The Midway and lower Wilcox (Marthaville) section and terminology were established by the senior writer[6] during his field

H. V. Howe, "Review of Tertiary Stratigraphy of Louisiana," *ibid.*, Vol. 17, No. 6 (1933), pp. 613–55; *Gulf Coast Oil Fields*, Amer. Assoc. Petrol. Geol. (1936), pp. 383–423.

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C. B. Claypool, "The Wilcox of Central Texas," unpublished Ph.D. dissertation (1933), Graduate School, Univ. of Illinois, Urbana, Ill.; abstract of dissertation (1933), Univ. of Illinois, Urbana, Ill.

H. V. Howe and J. B. Garrett, "Louisiana Sabine Eocene Ostracoda," *Louisiana Dept. Cons. Geol. Bull. 4* (1934), pp. 1–25.

[5] J. O. Barry, "Correlation of Wilcox Faunal Units of Louisiana" (abstract), *Program Amer. Assoc. Petrol. Geol.*, 26th Ann. Meeting (1941), p. 40; *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 5 (1941), p. 941.

R. J. LeBlanc, "Correlation of Upper Midway Fauna of Louisiana" (abstract), *Program Amer. Assoc. Petrol. Geol.*, 26th Ann. Meeting (1941), p. 40; *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 5 (1941), p. 941.

——— and J. O. Barry, "Fossiliferous Localities of Midway Group in Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 4 (1941), pp. 734–37.

G. E. Murray, Jr., "Midway Stratigraphy of Sabine Uplift" (abstract), *Program Amer. Assoc, Petrol. Geol.*, 26th Ann. Meeting (1941), p. 41; *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 5 (1941), pp. 941–42.

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J. O. Barry and R. J. LeBlanc, "Lower Eocene Faunal Units of Louisiana," *Louisiana Dept. Cons. Geol. Bull. 23* (1942), 208 pp.

[6] G. E. Murray, Jr., "Midway Stratigraphy of Sabine Uplift" (abstract), *Program Amer. Assoc. Petrol. Geol.*, 26th Ann. Meeting (1941), p. 41; *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 5 (1941), pp. 941–42.

———, "Geology of DeSoto and Red River Parishes, Louisiana," Ph.D. dissertation (1942), Graduate School, Louisiana State Univ., University, La. (Now in process of publication by Louisiana Geological Survey as *Bulletin 24*.)

CORRELATION CHART FOR LOWER CLAIBORNE, WILCOX & MIDWAY GROUPS OF TEXAS, LOUISIANA, MISSISSIPPI & ALABAMA

	TEXAS		LOUISIANA*	MISSISSIPPI		ALABAMA
CLAIBORNE GROUP	Weches greensand		Weches-Cane River greensand	Winona greensand		Winona greensand
	Queen City sand		Queen City sand	Neshoba Sand	Tallahatta formation	Tallahatta formation
	Reklaw formation		Reklaw formation	Sd. Basic member		
WILCOX GROUP	Carrizo formation		Carrizo formation	Wilcox Group (Undifferentiated)	Meridian Sand	Hatchetigbee formation
	Sabinetown formation		Sabinetown formation			Bashi formation
	Rockdale formation ?		Pendleton formation			Tuscahoma formation
	Seguin formation	Caldwell Knob member	Marthaville formation			Nanafalia formation
				Fearn Springs (sand) member		Fearn Springs (Sand) member
MIDWAY GROUP		Solomon Creek member	Hall Summit formation	Naheola formation		Coal Bluff member
						Naheola formation
	Wills Point Formation	Kerens member ?	Logansport formation			Matthews Landing (Marl) member
		Mexia member ?	Naborton formation			Porters Creek formation
	?		Porters Creek formation	Porters Creek formation		
	Kincaid formation		Kincaid formation	Clayton formation		Clayton formation

*Claiborne terminology based on section in northwest Louisiana (Bossier & Caddo Parishes)

FIG. 1

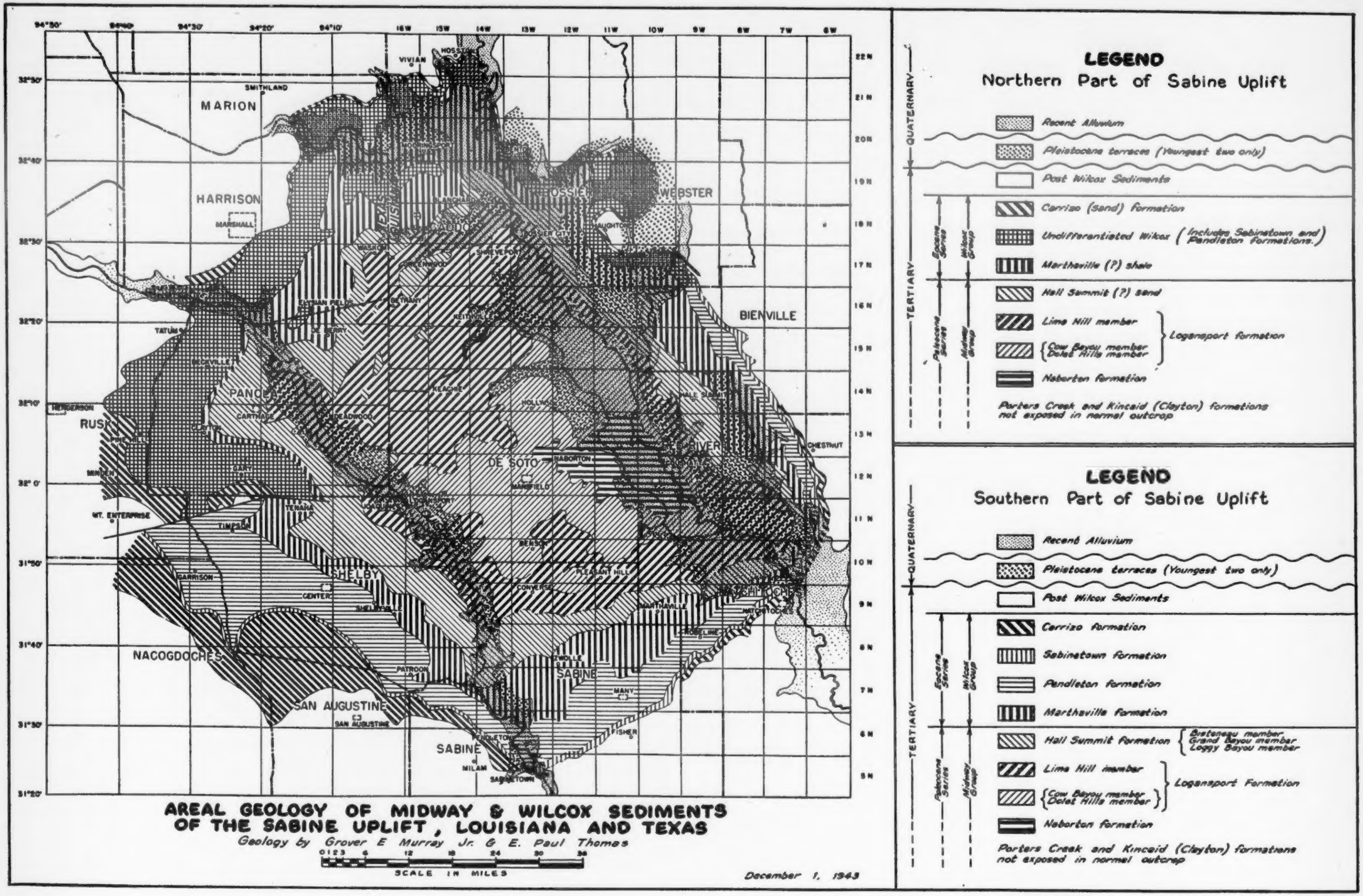
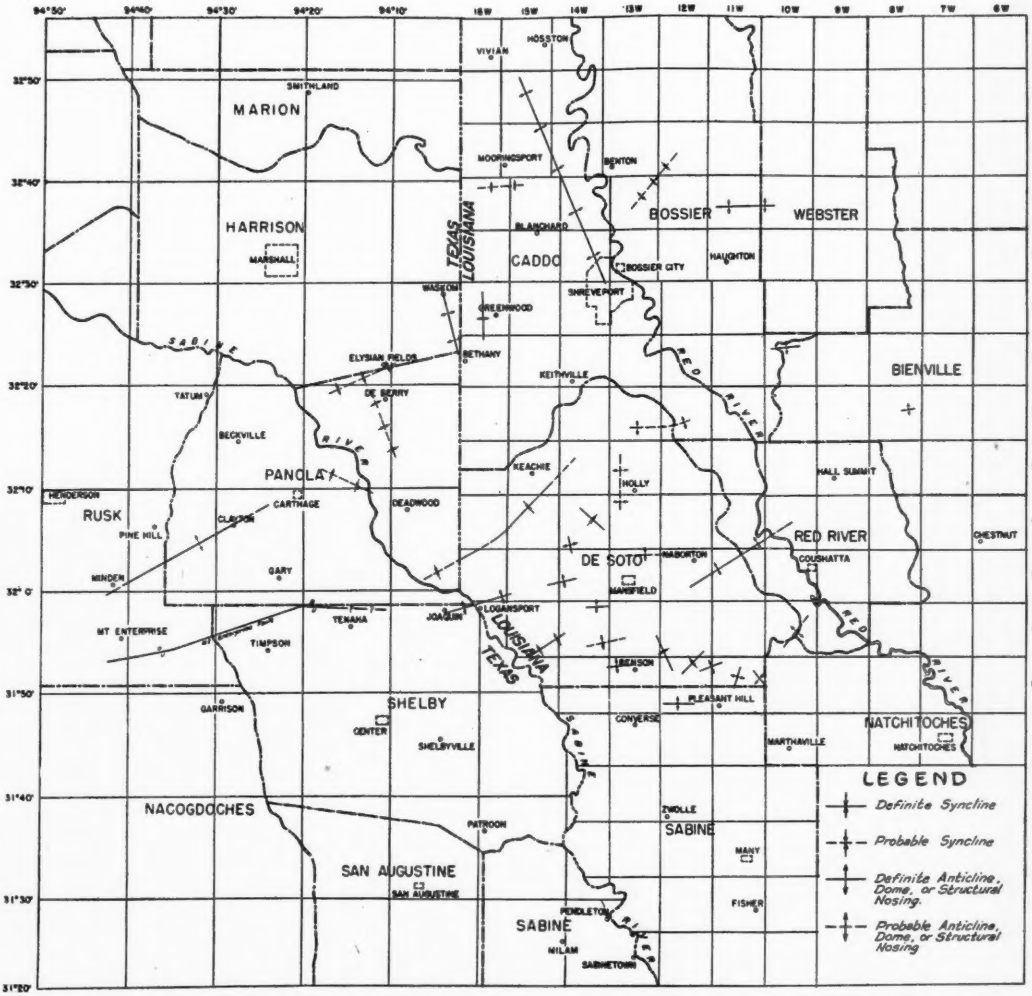

AREAL GEOLOGY OF MIDWAY & WILCOX SEDIMENTS
OF THE SABINE UPLIFT, LOUISIANA AND TEXAS
Geology by Grover E Murray Jr. & E. Paul Thomas
SCALE IN MILES
December 1, 1943
MARION
HARRISON
RUSK
PANOLA
SHELBY
NACOGDOCHES
SAN AUGUSTINE
SABINE
DE SOTO
WEBSTER
BIENVILLE
LEGEND
Northern Part of Sabine Uplift
Recent Alluvium
Pleistocene terraces (Youngest two only)
Post Wilcox Sediments
Carrizo (Sand) formation
Undifferentiated Wilcox (Includes Sabinetown and Pendleton formations.)
Marthaville (?) shale
Hall Summit (?) sand
Lime Hill member
Cow Bayou member
Dolet Hills member
Logansport formation
Naborton formation
Porters Creek and Kincaid (Clayton) formations not exposed in normal outcrop
QUATERNARY
TERTIARY
Eocene Series
Paleocene Series
Wilcox Group
Midway Group
LEGEND
Southern Part of Sabine Uplift
Recent Alluvium
Pleistocene terraces (Youngest two only)
Post Wilcox Sediments
Carrizo formation
Sabinetown formation
Pendleton formation
Marthaville formation
Hall Summit formation
Bistineau member
Grand Bayou member
Loggy Bayou member
Lime Hill member
Cow Bayou member
Dolet Hills member
Logansport Formation
Naborton formation
Porters Creek and Kincaid (Clayton) formations not exposed in normal outcrop

FIG. 2



STRUCTURAL AXES INDICATED BY MIDWAY & WILCOX SURFACE SEDIMENTS, SABINE UPLIFT, LOUISIANA & TEXAS

SCALE IN MILES
0 3 6 12 18 24

FIG. 3

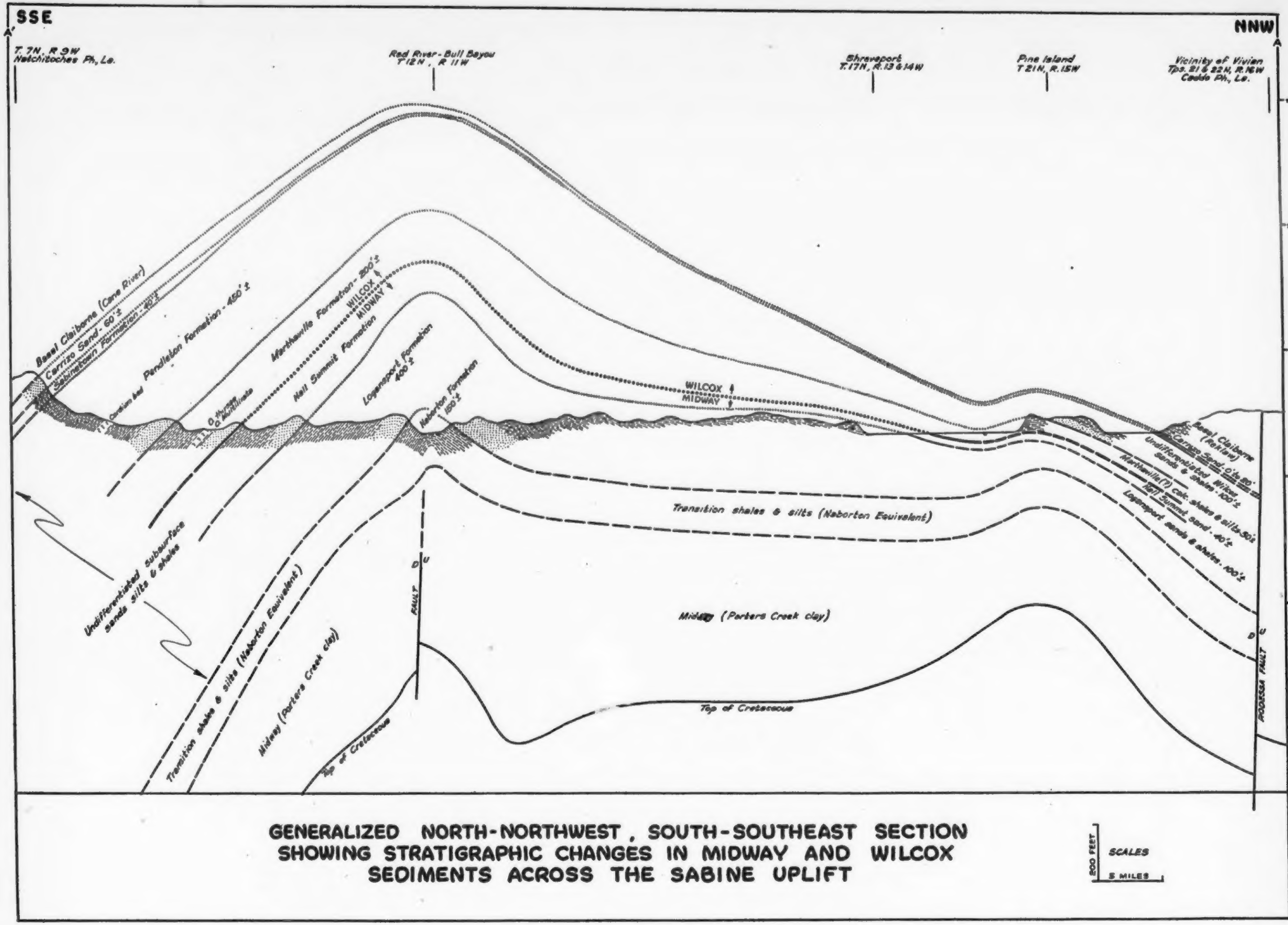

SSE
NNW
T. 7N., R. 9W
Natchitoches Ph., La.
Red River-Bull Bayou
T12N., R 11W
Shreveport
T.17N., R.13 & 14W
Pine Island
T 21N., R. 15W
Vicinity of Vivian
Tps. 21 & 22N., R. 16W
Caddo Ph., La.
+1200
+800
+400
Sea
0
Level
-400
-800
Basal Claiborne (Cane River)
Carrizo Sand - 60'±
Sabinetown Formation - 40'±
Pendleton Formation - 450'±
Marthaville Formation - 200'±
WILCOX
MIDWAY
Hall Summit Formation
Logansport Formation
400'±
Naborton Formation
150'±
Transition shales & silts (Naborton Equivalent)
Midway (Porters Creek clay)
Top of Cretaceous
FAULT
D
U
Undifferentiated subsurface
sands silts & shales
Basal Claiborne
(Reklaw)
Carrizo Sand - 0' to 80'
Undifferentiated Wilcox
Sands & shales - 100'±
Marthaville (?) calc. shales & silts - 30'±
Hall Summit sand - 40'±
Logansport sands & shales - 100'±
ROSSA FAULT
GENERALIZED NORTH-NORTHWEST, SOUTH-SOUTHEAST SECTION
SHOWING STRATIGRAPHIC CHANGES IN MIDWAY AND WILCOX
SEDIMENTS ACROSS THE SABINE UPLIFT
SCALES
200 FEET
5 MILES

FIG. 4

work in DeSoto and Red River parishes and adjoining areas. It was first presented in a manuscript now in the process of publication by the Louisiana Geological Survey which sponsored the field work. Wasem and Wilbert[7] proposed the middle Wilcox (Pendleton) terminology used herein; the upper Wilcox nomenclature, with some revisions, is taken from earlier reports.

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Location of Sabine Uplift

The Sabine uplift is a relatively flat-topped, roughly quadrate dome approximately 80 miles long and 65 miles wide situated in northwestern Louisiana and northeastern Texas. It is one of the major structural features of the Gulf Coastal Plain. Harris[8] named and defined the uplift and subsequent writers[9] have presented additional information on its structure and outline.

[7] Richard Wasem and Louis J. Wilbert, Jr., "The Pendleton Formation, Louisiana and Texas," *Jour. Paleon.*, Vol. 17, No. 2 (1943), pp. 181–95.

[8] G. D. Harris, "Rock Salt in Louisiana," *Louisiana Geol. Survey Bull. 7* (1907).
———, "Oil and Gas in Louisiana," *U. S. Geol. Survey Bull. 49* (1910). 192 pp.

[9] A. C. Veatch, "Geology and Underground Water Resources of Northern Louisiana," *Louisiana Geol. Survey Bull. 4* (1906), pp. 249–514.
G. C. Matson, "The Caddo Oil and Gas Field, Louisiana and Texas," *U. S. Geol. Survey Bull. 619* (1916). 62 pp.
——— and O. B. Hopkins, "The DeSoto-Red River Oil and Gas Field, Louisiana," *U. S. Geol. Survey Bull. 661-C* (1918), pp. 101–40.
E. T. Dumble, "The Geology of East Texas," *Univ. Texas Bull. 1868* (1920). 388 pp.
Sidney Powers, "The Sabine Uplift, Louisiana," *Bull. Amer. Assoc. Petrol Geol.*, Vol. 4, No. 2 (1920), pp. 117–36.
L. G. Huntley, "The Sabine Uplift," *ibid.*, Vol. 77, No. 2 (1923), pp. 179–81.
C. L. Moody, "Tertiary History of the Region of the Sabine Uplift, Louisiana," *ibid.*, Vol. 15, No. 5 (1931), pp. 531–51.

FIG. 4

On the surface the Sabine uplift is delineated by a large inlier of Midway and Wilcox sediments encircled by lower Claiborne deposits. The Claiborne-Wilcox contact is usually taken as the surface boundary of the uplift. Approximately two-fifths of the area so defined lies in northeastern Texas and three-fifths are found in northwestern Louisiana. The Texas part covers most of Shelby and Panola counties and parts of Sabine, San Augustine, Nacogdoches, Rusk, Harrison, and Marion counties, and the Louisiana part covers all of DeSoto and Red River parishes and parts of Bossier, Webster, Caddo, Bienville, Natchitoches, and Sabine parishes.

PHYSIOGRAPHY

The Midway-Wilcox inlier of the Sabine uplift area is situated in the north-central part of the western Gulf Coastal Plain physiographic province. The topography varies from rolling to hilly and the area is often referred to as the Wilcox "plain." This "plain" is encircled by a pronounced escarpment developed on the more resistant upper Wilcox and basal Claiborne beds. Several subdued escarpments or hilly belts are developed on the "plain" itself on the outcrops of the more massive sands of the Midway-Wilcox complex. The more shaly sediments give rise to a gently rolling topography similar to the famous "flatwoods" and "black belts" of the Midway black shales. Throughout the area, but more especially in the southern part, the larger streams tend to follow the outcrop belts of the more easily eroded sands. The local relief averages about 50 feet, but ranges up to more than 100 feet in the more rugged areas. The major portion of the area is drained by the Red and Sabine rivers and a minor part of the extreme western part lies within the Angelina River drainage basin. Recent alluvium and four Pleistocene terrace deposits mantle the Tertiary outcrops along the larger streams and especially along the Red River in Louisiana. The distribution of the alluvium and the lower Pleistocene terraces is indicated on the geologic map (Fig. 2). The distribution of these sediments in Bienville Parish is omitted because of insufficient evidence.

SURFACE STRATIGRAPHY

The sediments discussed in this report are of Paleocene and lower Eocene age. They lie below the Claiborne and above the typical Porters Creek (Midway) black shale. Lithologically they consist of a complex mass of lenticular sands, silts, and shales which contain thin, glauconitic, fossiliferous, marine lentils in the southern part of the area. This "complex" is actually a wedge-shaped mass (from present data) which ranges in thickness from more than 3,000 feet around the southern flank of the uplift to less than 400 feet around the northern flank. In this respect, as well as in all essential lithologic characteristics, this mass is similar to sediments of the same age across the Mississippi embayment in western Alabama and in Mississippi. The section along the Mississippi-Alabama state line, although thinner in its aggregate thickness, can be matched subdivision for subdivision with the section along the Sabine River.

Age

Howe,[10] Howe and Garrett,[11] Barry and LeBlanc,[12] and Murray[13] have summarized the history of the terminology and age assignment of the sediments of the Sabine inlier. In the latter papers (Barry, LeBlanc, and Murray) it was pointed out that Midway fossils occurred on the surface in sediments stratigraphically below the *Ostrea thirsae* zone (basal Wilcox of the type Alabama section) and above the typical Midway black shale (Porters Creek) in northwestern Louisiana in beds which had hitherto been considered to be Wilcox. The summarized data on which the Midway age assignment of these strata is based may be listed as follows.

1. Presence of 14 species of pelecypods, of which 3 are considered diagnostic
2. Presence of 23 species of gastropoda, of which 7 are considered diagnostic
3. Presence of 74 species of foraminifera, of which 5 are considered indicative
4. Similarity of these faunas to those of "Wills Point" and lower Seguin formations of Texas and to upper Porters Creek (including Matthews Landing marl), Coal Bluff[14] (restricted), and Naheola formations of Alabama and Mississippi, all of which have long been considered Midway in age
5. Similar lithology and stratigraphic position to upper Midway beds in western Alabama, Mississippi, and Texas, that is, sands, silts, and shales overlying typical Midway black clay and underlying beds containing *Ostrea thirsae* and its western Gulf Coast equivalent *Ostrea multilirata*
6. Absence of *bona fide* evidence indicating that sediments in question are Wilcox in age[15]

[10] H. V. Howe, "Review of Tertiary Stratigraphy of Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 6 (1933), pp. 613–55; *Gulf Coast Oil Fields*, Amer. Assoc. Petrol. Geol. (1936), pp. 383–423.

———, "Louisiana Petroleum Stratigraphy," *Oil and Gas Jour.*, Vol. 34, No. 8 (1936), pp. 98–111, 124–28; *Louisiana Dept. Cons. Gen. Min. Bull. 27* (1938), pp. 1–46.

[11] H. V. Howe and J. B. Garrett, Jr., "Louisiana Sabine Eocene Ostracoda," *Louisiana Dept. Cons. Geol. Bull. 4* (1934), pp. 1–25.

[12] J. O. Barry, "Correlation of Wilcox Faunal Units of Louisiana" (abstract), *Program Amer. Assoc. Petrol. Geol.*, 26th Ann. Meeting (1941), p. 40; *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 5 (1941), p. 941.

R. J. LeBlanc, "Correlation of Upper Midway Fauna of Louisiana" (abstract), *Program Amer. Assoc. Petrol. Geol.*, 26th Ann. Meeting (1941), p. 40; *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 5 (1941) p. 941.

——— and J. O. Barry, "Fossiliferous Localities of Midway Group in Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 4 (1941), pp. 734–37.

J. O. Barry and R. J. LeBlanc, "Lower Eocene Faunal Units of Louisiana," *Louisiana Dept. Cons. Geol. Bull. 23* (1942). 208 pp.

[13] G. E. Murray, Jr., "Midway Stratigraphy of Sabine Uplift" (abstract), *Program Amer. Assoc. Petrol. Geol.*, 26th Ann. Meeting (1941), p. 41; *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 4 (1941), pp. 941–42.

———, "Midway Microfauna of Northwestern Louisiana," *Bull. Am. Assoc. Petrol. Geol.*, Vol. 25, No. 4 (1941), pp. 738–42.

———, "Geology of DeSoto and Red River Parishes, Louisiana," Ph.D. dissertation (1942), Graduate School, Louisiana State Univ., University, La.

[14] The term Coal Bluff is used in this report as a member of the Naheola formation. It is considered to be uppermost Midway in age.

[15] E. W. Berry, "The Lower Eocene Floras of Southeastern North America," *U. S. Geol. Survey Prof. Paper 91* (1916). 481 pp.

———, "Revision of the Lower Eocene Wilcox Flora of the Southeastern States," *U. S. Geol. Survey Prof. Paper 156* (1930). 196 pp.

Berry described 53 species of plants from Naborton, DeSoto Parish, Louisiana, near the type locality of the Naborton formation of this report, which is the oldest lithologic unit exposed on the uplift. A review of Berry's check-lists shows that the Naborton flora can not be correlated satisfac-

Cyclic Depositional Pattern

In recent years publications by various authors working in widely separated areas on the Gulf Coastal Plain make reference to cyclic depositional patterns found in the Tertiary sediments. These cycles are also well shown on electric logs of many wells drilled into and through the Tertiary beds of the region. Such a pattern is present in the Midway-Wilcox complex of the Sabine uplift area and it is solely on this basis that the section can be subdivided. The following pattern is exhibited.

4. Massive to broken sand member
   Transition beds ordinarily containing lignite seams
3. Calcareous silt and shale member (locally glauconitic)[16]
   Transition beds, in places with lignites
2. Carbonaceous shale member (ordinarily absent in north part of uplift
   Transition beds, ordinarily with lignites
1. Massive to broken sand member

Insofar as possible, each complete cycle is designated a formation.

All the contacts are normally conformable and gradational, as indicated by the transition beds. Although the lenticularity of the individual beds is such that few of them can be traced very far along strike, the persistence of the different facies or members is remarkable and mapping can be carried on without undue difficulty if an over-all picture of the cyclic pattern is kept in mind.

GENERAL DESCRIPTION OF MEMBERS

Massive to broken sands.—The several sand members of the different Midway-Wilcox formations are lithologically similar, and generally can not be differentiated except by their stratigraphic position. They vary from massive to thin-bedded, from even-bedded to highly cross-bedded, from well to poorly sorted, and from very fine- to medium-grained. They ordinarily contain an abundance of more or less sandy clay or shale in the form of interbeds, pads, lenses, blocks, and small inclusions; some are arkosic. Silts and thin lignite seams are locally present. Where fresh, the sands in many places are slightly lignitic and are gray to white in color, but on the weathered outcrop they are tinted various shades of red, brown, and yellow, or are mottled. Clay-ball conglomerates are plentiful and occur at all horizons in these sand members, although they are more common in the lower parts. They consist of disoriented blocks of silt and shale embedded in

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torily with any of the Wilcox floras of Mississippi and Tennessee, although it shows affinities to the Adkerman flora in its almost entire absence of Leguminosae, which are very abundant in the younger floras. Some of Berry's "middle and upper Wilcox" localities are in sediments now believed to be lower Claiborne in age. His original correlation of the Naborton flora with the "upper middle Wilcox" flora of Tennessee and Mississippi (Berry, 1916, p. 57) was apparently based on the form ***Meniphylloides ettingshauseni*** Berry, which he considered a "Grenada" marker, but which is now known to have a long geologic range.

[16] These beds are normally only sparingly calcareous, but their lime content makes them the most distinctive and easily mapped unit in the cycle. For this reason they are called "calcareous" in this report.

a matrix of sand and the individual blocks range up to several feet in largest diameter. Petrified wood is a common adjunct of the sand members.

Carbonaceous shale member.—This facies typically consists of chocolate-brown to black, carbonaceous clays and lignitic silts with interbeds and lenses of gray to brown clays, silts, and fine sands. Locally large amounts of ferruginous and sideritic material and discoidal, argillaceous siderite concretions are present. These ironstones are much more abundant in the Midway sediments than they are in the Wilcox beds. Weathered outcrops of the clay vary from light gray to a distinctive purplish brown. Although these beds are normally even-bedded, the sandier facies are in places highly cross-bedded and lenticular and in some places contain clay-ball conglomerates. Well preserved fossil leaves are found in many outcrops and Foraminifera and Ostracoda have been found in this facies.

As in other Gulf Coast Tertiary sediments, the carbonaceous shale facies of the Midway-Wilcox complex are closely associated with beds of definite marine origin. They are normally found in the cyclic pattern only around the southern flank of the uplift, and northward they lens out or merge with the overlying calcareous silt and shale member.

Calcareous shale and silt member.—This facies has the most distinctive,lithologically, of any of the members of the pattern. It is typically composed of laminated, locally calcareous silts and silty shales. Where fresh, the beds are gray, buff, or black in color; upon weathering, they change to light gray to khaki to red or reddish brown. Although the structure of these beds is normally even-bedded, in places they are highly cross-bedded and locally grade into sands containing disoriented clay blocks. Common adjuncts are sideritic concretions, fossil leaves, and carbonized and silicified wood. Most of the glauconite and fossils found in the section occur in these beds.

The most characteristic feature of the calcareous silts and shales is the common occurrence of light-colored, silty, concretionary limestone boulders and calcareous, septarian concretions. The boulders are rounded to flattened and may weigh several tons. They are ordinarily blue-gray (fresh) to light brown (weathered) and commonly contain plant fragments; animal remains are present. They are obviously formed by secondary concretionary accumulation of the disseminated lime in the silts and shales; in some places they preserve the cross-bedding of the original materials. The septarians are discoid, generally 1–4 feet in diameter; they consist of partially crystalline, blue-gray limestone which commonly contain molluscan remains.

Transition beds.—The transition beds are commonly an interbedding of the facies above and below. They, like the other facies, are heterogeneous. Their most characteristic feature is the presence of persistent lignite seams, although lignites are not entirely restricted to this facies. These lignites provide almost the only horizons upon which detailed structural mapping can be done and that ordinarily only in local areas. The presence of subsurface lignites at these horizons is indicated on many electric logs.

Stratigraphic Section

The surface stratigraphic section used in this report is the following.

	Southern Half of Uplift	Northern Half of Uplift
Wilcox	Carrizo formation	Carrizo formation
	Sabinetown formation	Undifferentiated Wilcox
	Pendleton formation[17]	
	High Bluff member	
	Slaughter Creek member	
	Bayou Lenann member	
	Marthaville formation	Marthaville (?) shale
Midway	Hall Summit formation	Hall Summit (?) sand
	Bistineau member	
	Grand Bayou member	
	Loggy Bayou member	
	Logansport formation	Logansport formation
	Lime Hill member	
	Cow Bayou member	
	Dolet Hills member	
	Naborton formation—Chemard Lake lignite lentil at top	Not exposed

Paleocene Series

MIDWAY GROUP

NABORTON FORMATION

The term Naborton was proposed by the senior writer in 1942,[18] the name being taken from the village of Naborton in eastern DeSoto Parish. The formation includes all strata between the Midway black shale (Porters Creek) which is reached at about 100 feet in wells near Naborton and the overlying basal sand (Dolet Hills) member of the Logansport formation. The type locality consists of exposures along a local road between Louisiana Highway 9 and Bethlehem Church (between Naborton and Goss) in Secs. 3 and 4, T. 12 N., R. 12 W.

Naborton lithologic character is that of a typical calcareous silt and shale member of the cyclic pattern. A thick, well developed lignite (Chemard Lake lignite lentil—type locality, Coal Bed Springs in the NW. ¼ of Sec. 3, T. 11 N., R. 11. W., DeSoto Parish) marks the top of the formation in the southern part of its outcrop area. Approximately 175 feet of Naborton silt and shale is exposed on the surface.

The Naborton beds are the oldest Tertiary sediments exposed on the Sabine uplift, with the possible exception of the Bellevue dome in Bossier Parish, and their outcrop places the Tertiary apex of the uplift in and around the DeSoto-Red River-Bull Bayou field. The only known fossils of this formation are abun-

[17] The term Pendleton is preoccupied by the Pendleton sandstone of the middle Devonian of Indiana. If, in the future, it is considered advisable to abandon the Tertiary name Pendleton, the writers would suggest its change to Pendleton Ferry, since the type locality is the old Pendleton Ferry Landing.

[18] G. E. Murray, Jr., "Geology of DeSoto and Red River Parishes, Louisiana," Ph.D. dissertation (1942), Graduate School, Louisiana State Univ., University, La.

dant fossil leaves, fifty-three species of which were identified by Berry.[19] The Naborton is considered gradational from the underlying Porters Creek and is correlated with the upper silty shale facies of the Porters Creek of Mississippi.

LOGANSPORT FORMATION

The term Logansport was also proposed by the senior writer in 1942,[20] the name being taken from the town of Logansport, DeSoto Parish. The formation includes all strata overlying the Naborton beds and underlying the Hall Summit formation. Its type locality is a low bank on the eastern side of the Sabine River just above the bridge at Logansport. The beds comprising the Logansport formation exhibit one complete cycle of the depositional pattern, each member having been given a formal name by the senior writer as follows.

3. Calcareous silts and shales—Lime Hill member
2. Lignitic and carbonaceous shales—Cow Bayou member
1. Massive to broken sand—Dolet Hills member

Dolet Hills member.—The Dolet Hills member consists of about 100 feet of rather massive sand in its type area, which is the Dolet Hills south of Naborton (especially exposures along the road from Grove Hill church and cemetery to Naborton and in adjacent ravines in Sec. 6, T. 11 N., R. 11 W., in Sec. 1, T. 11 N., R. 12 W., and in Sec. 36, T. 12 N., R. 12 W.). Lithologically it can not be differentiated from other sands in the Midway-Wilcox complex. It interfingers along strike with the overlying and partially equivalent Cow Bayou member and is gradational from the underlying Naborton formation. In subsurface the member has been traced from Panola County east and north to Bienville Parish and south to the vicinity of Noble, Sabine Parish. It is brought to the surface on the Red River-Bull Bayou, Benson, Logansport, Spider, and Sutherlin structures and probably on the Holly structure.

Cow Bayou member.—This member was named for exposures along Cow Bayou in the SE. ¼ of Sec. 9 and NW. ¼ of Sec. 16, T. 10 N., R. 14 W., southwestern DeSoto Parish, approximately 3 miles southeast of Hunter on the gravel road to Converse. It has all the lithologic characteristics of a typical carbonaceous to lignitic shale member previously described under the cyclic pattern. The typical facies is best developed in and around the type locality, and the outcrop is largely restricted to central DeSoto Parish where its thickness averages 75–100 feet. It has been traced in subsurface throughout the same area as the Dolet Hills sand. Both its upper and lower contacts are transitional, the transition taking place through 5–15 feet of section.

Lime Hill member.—The Lime Hill member was named for exposures on and near Lime Hill in northeastern Sabine Parish, the type locality being along

[19] E. W. Berry, "The Lower Eocene Floras of Southeastern North America," *U. S. Geol. Survey Prof. Paper 91* (1916). 481 pp.

[20] G. E. Murray, Jr., "Geology of DeSoto and Red River Parishes, Louisiana," Ph.D. dissertation (1942), Graduate School, Louisiana State Univ., University, La.

Louisiana Highway 180 in the SW. ¼ of Sec. 23, T. 10 N., R. 11 W., and about 2½ miles northeast of Pleasant Hill. As the name indicates, the Lime Hill is a typical calcareous silt and shale member of the cyclic pattern. It is rather heterogeneous and sudden lithologic changes, both vertically and horizontally, into more sandy phases are not uncommon; it has a maximum thickness of 225 feet on the southern flank of the uplift. Clay-ball conglomerates are plentiful in this member in the northern part of its outcrop, and the section loses much of its calcareous content in this area. In places it is rather difficult to map, as indicated by dashed contacts on the geologic map. It is well exposed in and around the city of Shreveport where it consists of 50–75 feet of silty shales, silts, and sands with numerous concretionary boulders; a thin lignite seam is present near the top. The member has not been positively identified in Bossier Parish because of the paucity of outcrops, but it is believed to be present around the Bellevue dome, since the entire Midway-Wilcox section is apparently exposed on the northwest flank of this uplift near the village of Bellevue.

The Lime Hill member contains the oldest known marine fauna on the Sabine uplift. This fauna consists of Foraminifera, Ostracoda, and Mollusca which indicate an upper Midway age for the Logansport.[21] Fossil leaves are abundant in both the Cow Bayou and Lime Hill members, but the flora is very imperfectly known.

HALL SUMMIT FORMATION

This formation name was proposed by the senior writer in 1942,[22] the name being taken from the villge of Hall Summit in north-central Red River Parish. The type locality consists of exposures in the vicinity of this village in T. 14 N., R. 9 W. As in the case of the Logansport, this formation consists of one complete cycle of the cyclic pattern and the members have been named as follows.

3. Calcareous silts and shales—Bistineau member
2. Carbonaceous and lignitic silts and clays—Grand Bayou member
1. Massive to broken sand—Loggy Bayou member

[21] J. O. Barry, "Correlation of Wilcox Faunal Units of Louisiana" (abstract), *Program Amer. Assoc. Petrol. Geol.*, 26th Ann. Meeting (1941), p. 40; *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 5 (1941), p. 941.
R. J. LeBlanc, "Correlation of Upper Midway Fauna of Louisiana" (abstract), *Program Amer. Assoc. Petrol. Geol.*, 26th Ann. Meeting (1941), p. 40; *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 5 (1941), p. 941.
——— and J. O. Barry, "Fossiliferous Localities of Midway Group in Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 4 (1941), pp. 734–37.
J. O. Barry and R. J. LeBlanc, "Lower Eocene Faunal Units of Louisiana," *Louisiana Dept. Cons. Geol. Bull. 23* (1942). 208 pp.
G. E. Murray, Jr., "Midway Stratigraphy of Sabine Uplift" (abstract), *Program Amer. Assoc. Petrol. Geol.*, 26th Ann. Meeting (1941), p. 41; *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 4 (1941), pp. 941–48.
———, "Midway Microfauna of Northwestern Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 4 (1941), pp. 738–42.
———, "Geology of DeSoto and Red River Parishes, Louisiana," Ph.D. dissertation (1942), Graduate School, Louisiana State Univ., University, La.

[22] G. E. Murray, Jr., "Geology of DeSoto and Red River Parishes, Louisiana," Ph.D. dissertation (1942), Graduate School, Louisiana State Univ., University, La.

Both the upper and lower formational contacts and the contacts between the different members are gradational. The maximum known surface thickness of the formation is more than 300 feet in northern Sabine Parish. It thins toward the north and west to an estimated 150 feet in Shelby County and is apparently represented by at least part of a 25–50-foot broken sand section in Caddo Parish.

Loggy Bayou member.—The type locality of the Loggy Bayou member consists of exposures at and in the vicinity of Yellow Bluff in the NW. ¼ of Sec. 8 and the SW. ¼ of Sec. 5, T. 14 N., R. 10 W., near the junction of Love Lake and Loggy Bayou in Red River Parish. The member varies from 20 to 60 feet in thickness and consists of typical massive to broken sands with subordinate amounts of sandy shale and clay-ball conglomerates. It is sparingly glauconitic in the area west of Noble, Sabine Parish. This member is the most massive sand in the East Texas Midway-Wilcox section and reaches its maximum development along the escarpment west of Joaquin, Shelby County. Over the northern half of the uplift it becmes rather lenticular and difficult to trace, although it is well developed near Greenwood in Caddo Parish.

Grand Bayou member.—The type locality of this member consists of exposures in Secs. 19, 20, 29, and 30, T. 14 N., R. 9 W., Red River Parish. Lithologically it is typical carbonaceous shale. It reaches a maximum thickness of 80 feet on the south flank of the uplift. In the northeastern part of the uplift, it is believed to thin and merge with the overlying Bistineau member.

Bistineau member.—Exposures in T. 15 N., R. 10 W., in southwestern Bienville Parish and particularly those in Secs. 9 and 10 along Louisiana Highways 5650, 933, and 1154 from Ringgold to Lake Bistineau constitute the type locality of this member. It is typical calcareous silt and shale and attains a maximum thickness of 100 feet in its type area. Some of these beds are sparingly glauconitic in the area between Noble and the Sabine River in western Sabine Parish. Over the northern half of the uplift it is largely covered by Quaternary deposits. It is either absent or unrecognizable in Panola and Harrison counties and in Caddo Parish.

Hall Summit (?) *sand of northern part of uplift.*—The Hall Summit formation, with its three members, can be traced intact on the surface from Red River Parish around the south flank of the uplift to the Tenaha area of northern Shelby County. Here the upper two members lose their continuity and appear to grade laterally into a broken sand section. Contact relationships do not indicate a widespread overlap, but rather a merging of the upper Hall Summit shales into a sandy section. The 25–50-foot sand section mapped as Hall Summit (?) sand through Panola and Harrison counties and Caddo Parish probably includes some lower Marthaville sands in its upper part as well as the entire Hall Summit equivalent. The Midway-Wilcox contact in this area falls at some indefinite horizon within this sandy section.

Age.—Only two fossil localities are known in the Hall Summit sediments and

both occur in the lower part of the formation (transition beds at the base of the Grand Bayou member) in western Sabine Parish. *Polinices harrisii* Gardner, several other indeterminate gastropods, and the single pelecypod, *Anomia rufa* Barry, comprise the known fauna. No good fossil leaf localities were found in Hall Summit sediments. The formation is assigned to the uppermost Midway chiefly because of its stratigraphic position below the *Ostrea thirsae-O. multilirata* zones (Marthaville). These zones are considered lowermost Wilcox in the eastern and western Gulf Coastal areas, respectively.

Eocene Series

WILCOX GROUP

MARTHAVILLE FORMATION

The name Marthaville is rather an old one in geologic reports; it has long been applied to fossiliferous beds cropping out in and around the village by that name in northwestern Natchitoches Parish. The unit was recently expanded to include all beds above the Hall Summit formation and below the Pendleton formation and was raised to formational rank by the senior writer (1942).[23] As thus defined, the formation consists of three un-named lithologic units or members—a basal sand member, a middle lignitic shale member, and an upper calcareous silt and clay member. The members are all lithologically typical except that fossiliferous, glauconitic lentils are locally present in both the upper and lower units. The fossiliferous localities at Marthaville occur in the basal sand member. All contacts are transitional.

The maximum known surface thickness of this formation is about 300 feet in its type area. As in the case of the underlying formations, the different members are best developed around the southern end of the uplift in Sabine andNatchitoches parishes where fossiliferous marine lentils are common. The members can be traced without much difficulty along strike from the Red River-Bienville Parish line westward to the vicinity of the Mt. Enterprise fault in northwestern Shelby County. In Shelby County, the calcareous facies has perhaps the best development of any similar facies in the section. In this same area the middle member disappears and the basal sand is comparatively thin and difficult to trace.

The exact identity and correlation of the Marthaville section becomes obscure across the Mt. Enterprise fault in East Texas. North of the fault, there is a 50–75-foot calcareous silt and shale section which apparently represents most or all of the Marthaville section, although, as previously stated, the upper part of the underlying Hall Summit (?) may represent the lower part of this sequence. This calcareous shale section, which is shown as Marthaville (?) shale on the geologic

[23] G. E. Murray, Jr., "Geology of DeSoto and Red River Parishes, Louisiana," Ph.D. dissertation (1942), Graduate School, Louisiana State Univ., University, La.

map, may be mapped without serious interruption northward and northeastward to the Red River; it is particularly well exposed on the Pine Island uplift in northern Caddo Parish. The unit has also been identified at isolated exposures in Bossier and Bienville parishes, perhaps the best being at Swan Bluff in Bossier Parish.

Barry and LeBlanc[24] have ably detailed the Marthaville macrofauna in a recent paper and have linked the important guide fossils *Ostrea thirsae* (Gabb) and *Ostrea multilirata* Conrad. This closely ties the Marthaville formation with the Nanafalia formation of Alabama and the Caldwell Knob member of the Seguin formation of Texas.

PENDLETON FORMATION

The Pendleton formation was recently defined by Wasem and Wilbert[25] to include all sediments overlying the Marthaville formation and underlying the Sabinetown formation. The well known, highly fossiliferous exposure at the old Pendleton Ferry Landing, Sabine County, Texas, was designated as the type locality. Wasem and Wilbert have divided the formation into three members, each with its faunal zone, as follows.

Member	*Faunal Zone*
3. High Bluff	*Venericardia sabinensis*
2. Slaughter Creek	*Nuculana corpulentoidea*
1. Bayou Lenann	*Cardium toumeyi*

Bayou Lenann member.—The type locality of this member consists of exposures on and near Bayou Lenann in Sec. 12, T. 6 N., R. 13 W., Sabine Parish, Louisiana. In this area the member approximates 90 feet in thickness and from the base upward it characteristically consists of glauconitic, fossiliferous sand grading up into lignitic silts and sands with thin seams of lignite. The member has been traced from the vicinity of Geneva, Sabine County, to the vicinity of Hagewood, Natchitoches Parish. The *Cardium toumeyi* zone occupies a limited stratigraphic range at the base of the member and is characterized by the relative abundance of the zonal fossil.

Slaughter Creek member.—The type locality of this member consists of exposures along the banks of Slaughter Creek, Sabine Parish, and particularly a steep bluff near the head-waters of the stream in the southwest corner of Sec. 26, T. 6 N., R. 13 W. The member approximates 60 feet in thickness in its type area where it consists of fossiliferous, glauconitic sand with pipe-like limonitic nodules at the base which grades upward into 15–20 feet of fossiliferous clays with glauconitic sand lentils near the top. Overlying the clays are 20 feet of non-fossiliferous sand with calcareous concretions. A persistent lignite seam (the Stone Coal Bluff lignite) is present about 30 feet below the top of the member and is

[24] J. O. Barry and R. J. LeBlanc, "Lower Eocene Faunal Units of Louisiana," *Louisiana Dept. Cons. Geol. Bull. 23* (1942). 208 pp.

[25] Richard Wasem and Louis J. Wilbert, Jr., "The Pendleton Formation, Louisiana and Texas," *Jour. Paleon.*, Vol. 17, No. 2 (1943), pp. 181–95.

overlain by glauconitic, sparingly fossiliferous sand (Beulah Church lentil) in western Sabine Parish.

The fauna of the *Nuculana corpulentoidea* zone, which includes all the fossiliferous sediments in the Slaughter Creek member, is particularly well developed in the basal sand of the member. The fossiliferous beds exposed at Pendleton Ferry lie within this zone, which is characterized by the presence of *Nuculana corpulentoidea* (Aldrich) and *Turritella praecincta* Conrad.

High Bluff member.—This member, named for exposures at High Bluff on the Sabine River, Sabine Parish, approximates 130 feet in thickness in its type area. The typical section consists of a basal, glauconitic, fossiliferous sand overlain by silts and sands containing calcareous concretionary boulders. The silts and shales grade upward into 65 feet of thin-bedded lignitic silts and sands. The uppermost 30 feet of the member consists of cross-bedded sands. The *Venericardia sabinensis* zone at the base of this member is recognized only in the vicinity of Slaughter Creek in Sabine Parish.[26] It is easily recognized by the presence of *Venericardia sabinensis* Barry and the absence of *Venericardia densata pendletonensis* Gardner and Bowles which is common to the other Pendleton zones.

The thickness of the Pendleton formation is estimated to be 300 feet by Wasem and Wilbert in the type area. The formation thins both northeastward and northwestward along strike. On the Texas side the fossiliferous marine lentils lens out in Sabine County, but the three major subdivisions, although considerably thinner and altered lithologically toward the north, can be traced without difficulty to the Mt. Enterprise fault area. The extensive changes which take place in the Wilcox section in this area is discussed in more detail under "Undifferentiated Wilcox."

The rather large Pendleton fauna, consisting of Mollusca, Foraminifera, Ostracoda, corals, and echinoids, has been studied by several workers among which are Harris,[27] Claypool,[28] Howe and Garrett,[29] Barry and LeBlanc,[30] and Wasem and Wilbert.[31] On the basis of its fauna, the Pendleton formation is con-

[26] Richard Wasem and Louis J. Wilbert, Jr., "The Pendleton Formation, Louisiana and Texas," *Jour. Paleon.*, Vol. 17, No. 2 (1943), pp. 181–95.

[27] G. D. Harris, "The Lignitic Stage, Part 1, Stratigraphy and Pelecypoda," *Bull. Amer. Paleon.*, Vol. 2, No. 9 (1877). 103 pp.
———, "The Lignitic Stage, Part 2, Scaphopoda, Gastropoda, Pteropoda, and Cephalopoda," *Bull. Amer. Paleon.*, Vol. 3, No. 11 (1900). 128 pp.
———, "The Cretaceous and Lower Eocene Faunas of Louisiana," *Louisiana State Exp. Sta. Geol. Rept. for 1899*, Spec. Rept. 6 (1899), pp. 288–310.
——— and A. C. Veatch, "A Preliminary Report on the Geology of Louisiana," *Louisiana State Exp. Sta. Geol. Rept. for 1899*, Pt. 5, Sec. 2 (1899), pp. 45–138.

[28] C. B. Claypool, "The Wilcox of Central Texas," unpublished Ph.D. dissertation, Graduate School, Univ. of Illinois, Urbana, Ill. (1933); abstract of thesis, Univ. of Illinois, Urbana, Ill. (1933).

[29] H. V. Howe and J. B. Garrett, Jr., "Louisiana Sabine Eocene Ostracoda," *Louisiana Dept. Cons. Geol. Bull. 4* (1934), pp. 1–25.

[30] J. O. Barry and R. J. LeBlanc, "Lower Eocene Faunal Units of Louisiana," *Louisiana Dept. Cons. Geol. Bull. 23* (1942). 208 pp.

[31] Richard Wasem and Louis J. Wilbert, Jr., "The Pendleton Formation, Louisiana and Texas," *Jour. Paleon.*, Vol. 17, No. 2 (1943), pp. 181–95.

sidered equivalent to the Tuscahoma formation of Alabama and also to at least part of the "Rockdale" formation of Texas.

SABINETOWN FORMATION

The name Sabinetown was first applied as a formational name by Plummer[32] who took the name from the village of Sabinetown in Sabine County, Texas. The type locality is a high bluff on the Texas side of the river about $\frac{1}{4}$ mile below the old ferry landing. In his original usage of Sabinetown, Plummer included both the beds at Pendleton Ferry and those at Sabinetown in his Sabinetown formation and correlated all these sediments with the Bashi formation of Alabama. Howe and Garrett[33] pointed out the differences of the Pendleton and Sabinetown faunas and re-affirmed Harris' original correlation of the Pendleton and Sabinetown with the Tuscahoma and Bashi formations of Alabama, respectively. The writers recognize the validity of Sabinetown as a formational name, but herein restrict it to those beds lying above the High Bluff member of the Pendleton formation and below the Carrizo sand.

The generalized section exposed on the bluff at the type locality follows.

Wilcox Group
- Carrizo formation, 50 feet, white to brown, very fine-grained, massive to cross-bedded sand with abundant shale interbeds, partings and inclusions. Contact conformable and gradational
- Sabinetown formation
  - Upper member, 20 feet, silty, laminated, lignitic shale with glauconitic, cross-bedded, fine-grained sand
  - Lower (Pearson glauconite) member, 32 feet, fossiliferous, locally calcareous and indurated greensand and glauconitic sand with shale and clay interbeds and concretionary siderite

Lower (Pearson glauconite) member.—Justin Rukas first applied the name Pearson to this greensand section in his field notes while working for the Louisiana Geological Survey in Natchitoches Parish, the name being taken from the railway station by that name north of the town of Natchitoches. The name first appeared in print in a publication by Wasem and Wilbert,[34] who used it as applied by Rukas. This member is typically a fine-grained greensand or glauconitic sand which commonly contains considerable concretionary ironstone. It reaches its maximum development in the Sabinetown area, thinning both northeastward and northwestward along strike. It extends from Bienville Parish to southern Rusk County and makes a valuable mapping unit over much of its outcrop belt. Locally in Shelby County this member is absent; in these areas it was apparently truncated by the streams which deposited the Carrizo sand. However, most of the exposures of both the upper and lower contacts show them to be conformable and gradational.

[32] F. B. Plummer, "The Geology of Texas, Cenozoic Systems in Texas," *Texas Univ. Bull. 3232*, Pt. 3 (1933), pp. 519–818.

[33] H. V. Howe and J. B. Garrett, Jr., "Louisiana Sabine Eocene Ostracoda," *Louisiana Dept. Cons. Geol. Bull. 4* (1934), pp. 1–25.

[34] Richard Wasem and Louis J. Wilbert, Jr., "The Pendleton Formation, Louisiana and Texas," *Jour. Paleon.*, Vol. 17, No. 2 (1943), pp. 181–95.

Upper (shale) member.—Whenever the lower glauconitic member of the Sabinetown is present, it is normally overlain by 2–30 feet of lignitic silty shale with subordinate amounts of carbonaceous clay, silt, and sand. These beds are in places sparingly glauconitic. As at Sabinetown Bluff, these shales normally are transitional upward into the overlying Carrizo sand, but at some localities the contact is sharply defined and at still other localities there is definite evidence of local erosion.

The maximum total thickness of the Sabinetown formation is estimated to be about 60 feet in the type area. Elsewhere it ranges from 10 to 25 feet, and, in its northernmost extension in southern Rusk County, it ranges down to less than 5 feet.

Harris[35] was the first to make a detailed study of the rather large and varied Sabinetown fauna and to correlate it with the Bashi fauna of Alabama. This correlation has been substantiated by Howe and Garrett[36] and Barry and LeBlanc.[37] The fauna occurs in the lower greensand member and is characterized by *Venericardia bashiplata* Gardner and Bowles.

UNDIFFERENTIATED WILCOX OF NORTHERN UPLIFT AREA

Extensive and perplexing facies changes take place in the East Texas Wilcox section across the Mt. Enterprise fault. It may be that movements along the fault during Wilcox time helped produce this condition. As previously indicated, the middle calcareous shale member of the Pendleton formation can not be identified north of the fault and the Pendleton section therefore becomes undifferentiable. A feather edge (2–4 feet) of the lower Sabinetown greensand overlain by a few feet of the upper shale member is found a few miles north of the fault at its northernmost outcrop. The contact relationships, the thinness of the section, and the occurrence of the upper shale member in its normal position indicate that this was the area of maximum advance of the Sabinetown sea and that the formation is not necessarily overlapped unconformably by the Carrizo. Unfortunately, the area on the eastern flank of the uplift where similar facies changes apparently occur in the Wilcox is extensively covered by Quaternary deposits and the Tertiary outcrops are so isolated and fragmentary that little information can be gleaned from them.

For the foregoing reasons the section overlying the Marthaville (?) shale and underlying the Carrizo sand around the northern half of the uplift is called simply undifferentiated Wilcox in this report. These beds consist of lenticular sands, silts, and shales ranging from 50 to 100 feet in thickness. Clay-ball conglomerates are

[35] G. D. Harris, "The Cretaceous and Lower Eocene Faunas of Louisiana," *Louisiana State Exp. Sta. Geol. Rept. for 1899*, Spec. Rept. 6 (1899), pp. 289–310.

[36] H. V. Howe and J. B. Garrett, Jr., "Louisiana Sabine Eocene Ostracoda," *Louisiana Dept. Cons. Geol. Bull. 4* (1934), pp. 1–25.

[37] J. O. Barry and R. J. LeBlanc, "Lower Eocene Faunal Units of Louisiana," *Louisiana Dept. Cons. Geol. Bull. 23* (1942). 208 pp.

fairly abundant at all horizons and the beds are normally transitional above and below. The transition facies contain some rather persistent lignite seams. No marine material or fossils have been noted in this section, but the lower transition beds contain an abundance of well preserved fossil leaves and a detailed study of these leaves will doubtless yield valuable information regarding the more exact correlation of these beds. A review of Berry's[38] check lists and some preliminary work done by the junior writer on several localities at this horizon in northern Caddo Parish and Harrison County indicates a flora more closely allied to that of Berry's "Grenada" (now known to be basal Claiborne) than to his Ackerman flora.

CARRIZO FORMATION

The beds commonly called Carrizo in East Texas consist of massive to broken, fine-grained sands with subordinate amounts of sandy shale and clay. The sands are typically non-glauconitic and non-arkosic (a fact which serves to differentiate them from some of the other Midway-Wilcox sands). Their structure ranges from thin- and even-bedded to massive to highly cross-bedded; their grain size varies from very fine to coarse; and their degree of sorting varies from good to poor. When fresh, these sediments are generally light gray to white, but on the outcrop they are commonly stained some shade of red or brown. The associated shales and clays occur as inclusions, pads, partings, interbeds, and lenses. Disseminated glauconite is rather abundant at the top of the formation around the southwestern flank of the uplift, and, at a few localities on the southern end of the uplift, lentils of sparingly glauconitic sand occur in the main body of the formation.

The Carrizo is about 60 feet thick at Sabinetown and increases to a maximum of 125 feet in San Augustine County. It decreases to approximately 50 feet in northern Rusk County and lenses out in the vicinity of Marshall in Harrison County, where the Reklaw lies directly on undifferentiated Wilcox. The Carrizo is believed absent in this area due to simple non-deposition of the facies. Around the northern flank of the uplift the exposures are generally poor, but isolated outcrops show 10–20 feet of Carrizo-type sand beneath the Reklaw and above the silty to sandy shales and arkosic sands of the undifferentiated Wilcox. The formation is believed to be fairly persistent over this area. Locally the thin Carrizo sands grade laterally into sandy shales.

An anomalous condition is present across Sabine Parish from Sabinetown to Robeline. Here the Sabinetown formation is separated on the surface from the Cook Mountain (middle Claiborne) by about 300 feet of more or less massive, fine-grained, non-glauconitic sand and the entire Cane River section is absent. Many field geologists attribute its absence to a large strike fault which throws the Sparta sand down against the Carrizo sand. This is perhaps the simplest explanation and is supported by the presence of numerous surface faults in this area, but

[38] E. W. Berry, "The Lower Eocene Flora of Southeastern North America," *U. S. Geol. Survey Prof. Paper 91* (1916). 481 pp.

there is also some evidence that the Cane River may be absent due to the simple non-deposition of the facies. This section definitely thins eastward from Sabinetown and is represented by less than half its normal thickness in a bore-hole ½ mile south of Sabinetown Bluff.

Typical Carrizo sand appears again in its normal stratigraphic position in northern Natchitoches Parish where it has a thickness of 75–100 feet. This section extends on into Bienville Parish, thinning northward. It disappears beneath quaternary deposits and reappears as 10–20 feet of shaly sand in central Bossier Parish.

The lower Carrizo contact has been discussed previously. It is considered to be essentially conformable and only locally disconformable. The upper Carrizo contact exhibits some very interesting changes around the uplift. In Sabine and San Augustine counties the "Cane River" lies disconformably on the Carrizo. The basal few feet of the "Cane River" consists of a persistent, basal sandy concentrate of the type so common at the base of the various marine Tertiary formations through the Gulf Coastal Plain. At the contact proper materials of both the overlying and underlying facies are heterogeneously mixed. Coarse-grained glauconite is present in the upper few feet of the Carrizo and disappears within a short distance downward in the section. It is believed that this type of contact evidences a concerted marine advance over a low deltaic plain accompanied by wave erosion and re-working of the underlying beds. This contact is, therefore, considered disconformable. Northward along strike the Reklaw-Carrizo contact becomes progressively less distinct and more gradational and on the north flank of the uplift there is little or no evidence for a widespread erosional break at this horizon. It is obvious that the marine advance was much less strong in this area and that non-marine deposition gave way more gradually to marine deposition. Identical conditions exist at the Tallahatta-Meridian[39] contact in western Alabama and Mississippi.

Age.—The Carrizo formation of east Texas has been considered to be basal Claiborne by many Texas geologists and to be upper Wilcox by others, the recent trend being to accept it as Claiborne in age. The reasons usually given are that it is lithologically different from the Wilcox sands and that it is separated from the underlying Wilcox by an erosional unconformity. The writers of this paper consider the Carrizo of the Sabine uplift area to be uppermost Wilcox because: (1) regional correlation across the Mississippi embayment indicates uppermost Wilcox age for the formation (Fig. 1); (2) lithologically the Carrizo is not necessarily definitely Claiborne in aspect; (3) there is insufficient evidence for drawing a widespread unconformity at the base of the formation in this area; and (4) the

[39] The term Meridian is applied in this report to about 90 feet of sand lithologically the same as the Carrizo and underlying the Tallahatta formation at Meridian and elsewhere in Mississippi and western Alabama.

only available paleontological evidence (fossil leaves identified by Berry[40]) suggest a Wilcox age. The first three points are discussed in some detail. The fourth is self-explanatory.

As indicated on the correlation chart (Fig. 1), there is a close lithologic and faunal tie in the lower Claiborne section across the Mississippi embayment. In eastern Mississippi about 90 feet of Tallahatta "buhrstone" is overlain by 20 feet of coarse-grained Winona greensand containing *Ostrea sellaeformis* var. *lisbonensis*. This greensand is one of the most distinctive lithologic units in the Tertiary sequence of the Gulf Coastal Plain. Northward along strike a sand wedge, called the Neshoba sand by the junior writer,[41] comes into the section between the Winona and Tallahatta and the Tallahatta gradually changes facies to micaceous, flaky shales and glauconitic to non-glauconitic sands with subordinate amounts of claystone. A similar condition occurs across the Sabine uplift. In Sabine and San Augustine counties the "Cane River" section consists of an upper 40–50 feet coarse-grained greensand containing *Ostrea sellaeformis* var. *lisbonensis* underlain by about 50 feet of light-colored, flaky shales with some glauconitic sand and sandy limestone boulders. In Nacogdoches County these two members are separated by the entrance of the Queen City sand wedge into the section; the upper greensand is called the Weches and the lower shale section is called the Reklaw. This tri-partite section carries around the northern flank of the uplift and southward to the area east of Shreveport. The Reklaw shales of the northern part of the uplift are lithologically similar to the Tallahatta shales of central Mississippi (Montgomery County) except that they contain fossiliferous ironstones (absent in the Tallahatta) and lack the siliceous claystone ledges present in the Tallahatta. It is believed that the upper part of the Cane River "greensand-marl" of Natchitoches and Bienville parishes is equivalent to the Weches and Winona and that the lower, more marly part of the Cane River is the equivalent of the Tallahatta "buhrstone" of eastern Mississippi. With this correlation and the close lithologic and faunal tie of the Bashi and Sabinetown formations, it seems inescapable that the Carrizo and Meridian sands are time, as well as lithologic, equivalents.

The problem, then, becomes one regarding the age of the Meridian sand, which has been considered of uppermost Wilcox age by the junior writer[42] on the basis of field relationships in eastern Mississippi and western Alabama. In the area between Meridian, Mississippi, and the Tallahatta Hills of Choctaw County, Alabama, which is the type area of the Tallahatta formation, the Meridian thins from a 90-foot section to a feather edge or complete absence. Through this same area the overlying Tallahatta maintains constant lithologic character and thick-

[40] E. W. Berry, "Additions to the Flora of the Wilcox Group," *U. S. Geol. Survey Prof. Paper 131* (1922), pp. 1–21.

[41] Emil Paul Thomas, "The Claiborne," *Mississippi State Geol. Survey Bull. 48* (1942). 96 pp.

[42] *Ibid.*

ness. There is evidence of a widespread erosional break at the base of the Tallahatta here, but the lower Meridian contact is essentially conformable and transitional. For these reasons, it is believed that the Meridian represents a sandy facies of the type Hatchetigbee shale (uppermost Wilcox of Alabama).

Although the Carrizo is lithologically most similar to the Sparta sand of the Claiborne, the thesis that it has a definite Claiborne aspect is unsound, since it can not be differentiated from some of the Midway-Wilcox sands merely on the lithologic basis. It is true that the Carrizo has a much more widespread lateral and downdip distribution than the sands lower in the section, but it is also true that some of the sands lower in the section are more widespread than is commonly recognized. Too, much of the wide areal distribution of the Carrizo is probably more apparent than real and is in part due to its position beneath a persistent marine horizon.

The contact relationships of the Carrizo have already been discussed. It is believed that it is more logical to explain the erosional features sometimes found at the lower contact as local channelling by the agencies which deposited the Carrizo than it would be to postulate a widespread unconformity at this horizon in the face of numerous exposures of conformable and transitional relationships with the underlying beds. The preponderance of evidence is rather for a distinct and widespread erosional hiatus at the top of the Carrizo and Meridian sands on both sides of the embayment.

Depositional Conditions and History

From a broad viewpoint, and even in many minor details, the Midway and Wilcox sediments of the Sabine uplift area are surprisingly similar, both in lithologic and faunal characteristics, to the sediments of the same age in eastern Mississippi and western Alabama. The same appears to be true southwest as far as south-central Texas. Such similarity could only be brought about by relatively uniform depositional conditions throughout the area during Midway and Wilcox time.

We may glean considerable information regarding the conditions under which these sediments were deposited from the rocks themselves. With this as a starting point and applying the rule of uniformitarianism, we may deduce a logical, though perhaps incomplete, picture of Midway-Wilcox time.

The presence of glauconite and marine fossils are generally conceded to be *prima facie* evidence of a marine origin of the enclosing sediments, while lignites are obviously of non-marine origin. The repeated occurrence of these two facies (in some places within a few feet of vertical range) throughout more than 3,000 feet of Midway-Wilcox sediments around the southern flank of the uplift, and many miles downdip in subsurface, could take place only on a low coastal plain of considerable width which was sinking at nearly the same rate as that at which the sediments were being deposited, and which was subject to innumerable minor retreats and advances of the strand line and re-entrants of the sea. Similar condi-

tions are present around the Mississippi delta to-day, and to them we might well apply the adjective "deltaic" after Russell and Fisk.[43]

In a deltaic environment there are three contemporaneous, yet dissimilar, types of deposits or facies. Offshore, there is shallow marine deposition. Along the coastal apron are coastal marshes, rich in organic material and containing innumerable meandering streams and lakes which support an abundant brackish-water fauna. These streams and lakes rework and sort deposits as they erode their banks at one place and deposit the eroded materials elsewhere. Along the strand line the marine materials and marsh deposits are closely and heterogeneously admixed by wave action; marine shells are sometimes carried far back on the marsh by inundations resulting from tropical storms. Landward the marsh deposits grade into the fluviatile sands, gravels, silts, and clays of the broad river flood-plains, also with meandering streams which erode at one place while depositing at another. Calcareous, back-swamp clays and peaty materials are common in this environment. It is believed that all of the various Midway-Wilcox lithologic types can be assigned to one of these three environments.

Each cycle of the Midway-Wilcox depositional pattern was apparently initiated by a rather sudden increase in the gradients of the streams which were depositing their loads upon the broad, low coastal plain. With an increase in gradient and in competence, the streams carried their finer materials farther seaward and deposited their sandy materials upon the coastal plain. Over much of the plain this change was reflected by a gradual transition upward into coarser sediments, but, locally, the streams eroded or channelled down into the underlying materials. At the same time these streams also eroded their banks and incorporated the "cavings" in their deposits as the clay-ball conglomerates that are so abundant in the coarser sediments.

As equilibrium was again approached, the streams lost much of their competency and a gradual transition to a more marshy environment occurred. During this transition, conditions were ideal for the deposition of lignite and carbonaceous clays. Toward the end of the cycle, optimum conditions existed for the deposition of the calcareous beds with their marine lentils. A subsequent rejuvenation of the streams set the whole process again in motion.

Briefly, the Midway-Wilcox depositional history of the Sabine uplift area appears to be as follows. Deposition of the basal, marly and sandy Midway sediments (Kincaid) was followed by shallow marine (pro-deltaic) conditions. During this time the widespread Porters Creek clay was deposited. A deltaic environment replaced the shallow marine environment of the Porters Creek and the Naborton formation and its equivalent-sediments were laid down over a wide area. Then a

[43] R. J. Russell, "Physiography of Lower Mississippi River Delta," *Louisiana Dept. Cons. Geol. Bull. 8* (1939), pp. 1–199.

R. J. Russell and R. D. Russell, "Mississippi River Delta Sedimentation," *Recent Marine Sediments*, Amer. Assoc. Petrol. Geol. (1939), pp. 153–77.

H. N. Fisk, "Geology of Avoyelles and Rapides Parishes," *Louisiana Dept. Cons. Geol. Bull. 18*, pp. 117–27.

rejuvenation of the streams initiated the Logansport cycle and subsequent rejuvenations caused the Hall Summit, Marthaville, and Pendleton cycles. On the northern half of the uplift fluviatile conditions existed during much of this time. Local erosional channels and clay-ball conglomerates are much more abundant in this area than at the south, but no widespread unconformities can be postulated in the face of the transitional contacts throughout the section.[44] There are no bauxitic or lateritic horizons in the section, which would indicate a long period of non-deposition and subaerial weathering at the end of Midway time, as there are farther north in Arkansas and across the embayment in Mississippi and eastern Alabama. Some of the thinning of the Midway-Wilcox section across the uplift may be due to structural movement during that time, since the uplift has long been an active positive area.[45]

During Sabinetown time, the sea advanced far onto the uplift and contemporaneous non-marine deposition occurred north of its maximum advance. Shortly thereafter, rejuvenation of the streams brought on the deposition of the Carrizo sand blanket, and then a concerted advance of the Claiborne sea over the uplift closed the Midway-Wilcox sedimentation.

STRUCTURAL GEOLOGY

Economically, a surface mapping method has value only if it reflects local structure. The work on the Sabine uplift has shown that the surface exposures reflect subsurface structure to a previously unsuspected extent. Although the extreme lenticularity of the individual beds makes detailed structural mapping impossible except locally on some of the lignite seams, the areal distribution of the different units reflects the larger structural features with considerable fidelity.

Figure 3 shows the structural axes indicated by the field work. Practically all of the larger structural features of the uplift have surface reflection except in those areas where the Tertiary is mantled by Quaternary deposits. The major structures indicated are: Red River-Bull Bayou, Logansport, Pleasant Hill, Zwolle (?), Carthage, Waskom, Converse, Pine Island, Mt. Enterprise fault, Bellevue, and the Carthage-Clayton-Pine Hill area of Panola and Rusk counties. Smaller structures indicated by the senior writer's more detailed work in Red River and DeSoto parishes and adjacent areas are: Benson, Spider, Sutherlin, Holly, Grogan-Ramsey, Lake Bistineau, Grand Cane, Ajax, Lake End, Caspiana (?), and Elm Grove (?). This list includes a rather imposing percentage of the oil and gas fields on the uplift and it emphasizes that the method employed is economic and feasible.

[44] A rather widespread clay-ball conglomerate is found in the northern half of the uplift at the basal contact of the Hall Summit (?) sands; this clay-ball conglomerate might indicate a relatively large break at this horizon.

[45] C. L. Moody, "Tertiary History of the Region of the Sabine Uplift, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 5 (1931), pp. 531–51.

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STRUCTURAL GEOLOGY OF SOUTHEASTERN VIRGINIA[1]

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ABSTRACT

New data are presented that alter somewhat the basic concepts of the geology of the Coastal Plain in Virginia. These may be summarized as follows: Upper Cretaceous deposits have a rather wide range of distribution south of the James River but are apparently lacking immediately north of the James River; Eocene sediments, generally less than 100 feet thick south of the James River, are known to be several hundred feet thick throughout most of the Coastal Plain north of the James River and thicknesses up to about 800 feet are known at Fort Monroe. A structural contour map on the Eocene-Miocene contact shows that that boundary is gently but definitely warped.

Interpretations based on these data are as follows. The lack of Upper Cretaceous sediments at Newport News and Fort Monroe is ascribed to pre-Eocene channeling rather than to relative uplift of that area with respect to Norfolk. Post-Upper Cretaceous channel filling is not the complete explanation for all the thickening of sediments north of the James River and that area is believed to have subsided throughout Eocene time. Subsidence is accounted for by faulting of the basement rock. The fault is thought to trend westward along the James River and approach the Fall Zone; the maximum displacement along the postulated fault, from 300 to 600 feet, occurs in the Hampton Roads area. In post-Miocene time the area was gently folded as a result of settling movements along a pre-existing fault or series of faults.

Geophysical data are drawn upon to substantiate the interpretations presented and to show the probable similarity of the Cape Fear region in North Carolina to the Hampton Roads region in Virginia.

INTRODUCTION

A continuing investigation of ground-water resources has been carried on in southeastern Virginia since 1937 as a coöperative project of the Virginia Geological Survey and the United States Geological Survey. The Coastal Plain south of the James River has been covered in detail, considerable information is at hand on the geology and hydrology of the lower York-James Peninsula, and miscellaneous data are available on the more northerly parts of the Coastal Plain west of Chesapeake Bay.

The field work at first was largely devoted to making county surveys in which strictly hydrologic data were emphasized but in the last 3 years considerable time was spent in supervising test-drilling projects in the development of Army, Navy, and municipal ground-water supplies, as a result of which a great deal of detailed and accurate geological information has become available. Very recently much time was spent in studying the samples of well cuttings collected during the period of intensified drilling. Macrofossils, where available, were submitted to Horace G. Richards of the Philadelphia Museum for determination and all samples at hand have been worked over in order to separate their foraminiferal content. Sediments were washed in a 150-mesh screen and dried, after which the foraminifera were floated out with carbon tetrachloride and submitted to J. A. Cushman for determination. Many macrofossil determinations have been particu-

[1] Released by permission of the director, Geological Survey, United States Department of the Interior and the State geologist, Geological Survey, Virginia Conservation Commission. Manuscript received, November 6, 1944.

[2] Associate geologist, Geological Survey, United States Department of the Interior.

larly helpful but it has been found that foraminifers are, in general, considerably more useful than the macrofossils because of their greater abundance.

The fossil determinations have been invaluable and, insofar as fossils have been available, the determinations have established formational boundaries throughout the area. In addition to defining formations, certain geologic facts have been brought forth by the studies which seem to alter considerably the common conception of the make-up of the Virginia Coastal Plain, and perhaps the whole Atlantic Coastal Plain as a province. A structural history of a part of the Virginia Coastal Plain province is presented herewith based on available positive data, and suggestions are made about the structure where only incomplete data are present. The structural interpretations presented here must not be considered as final in any sense; there is hardly much doubt that the picture will change radically as new information becomes available. Rather, the intent of this paper is to show that the old concept, based on fragmentary data, is incomplete in its scope and that workers along the Atlantic seaboard should keep in mind other possibilities which heretofore have not generally been considered.

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The work in Virginia has been carried out under the direction of O. E. Meinzer, chief of the Ground-Water Division of the United States Geological Survey. Members of the United States Geological Survey and the Virginia Geological Survey, Arthur Bevan, State geologist, merit particular thanks for their criticism of the manuscript. Robert Bloomer of the faculty of the University of Virginia gave freely of his time in discussion of the paper. Miss N. Morris, of this office, prepared nearly all the well cuttings for study of foraminifers and insoluble residues, and assisted in the preparation of the illustrations.

The coöperation of drillers in the area has made possible the acquisition of suites of well cuttings for study. Appreciation of this service is expressed to O. C. Brenneman of Providence Forge, the Layne-Atlantic Company of Norfolk, Jesse Minton of Smithfield, the Mitchells Pump and Well Company of Petersburg, W. S. Reynolds of Walkerton, and the Sydnor Pump and Well Company and the Virginia Machinery and Well Company of Richmond.

Paleontological determinations by J. A. Cushman and H. G. Richards have established geological boundaries in many areas and have shown the existence of Upper Cretaceous strata at several localities. Their work has been of the greatest value.

WORK OF PREVIOUS INVESTIGATORS

In 1904 Darton published on the Norfolk-Newport News, Virginia, Quadrangle.[3] In that publication he discussed the results of deep drilling at Fort Monroe and Norfolk and presented data which made possible for the first time a three-dimensional picture of a large part of the Coastal Plain. Bedrock lies at a

[3] N. H. Darton, "Norfolk," *U. S. Geol. Survey Geol. Atlas Folio 80* (1902), p. 3.

depth of 2,246 feet below the surface at Fort Monroe. The Potomac group of sediments of Lower Cretaceous age, which rests on the granitic bedrock, was considered to be 1,300 feet thick at Fort Monroe; above the Potomac group are marine sediments of Upper Cretaceous age. These were positively identified by fossils in cuttings of the Norfolk waterworks well (located in western Princess Anne County, about 6 miles east of Norfolk), and were found to be about 100 feet thick. Glauconitic sediments of Eocene age (Pamunkey group) were apparently about 75 feet thick at the Norfolk waterworks well but were thought to be about 125 feet thick at Lamberts Point, Norfolk. Above the Eocene sediments, the marls and sandy marls of the Chesapeake group of Miocene age were found to be about 625 feet thick at the waterworks well; near-surface deposits consist of 25 feet of Quaternary terrace sands and clays.

Clark and Miller[4] in 1913 published on the Coastal Plain of Virginia. Their work consists of a detailed study of the outcropping formations. Strata older than the Miocene are exposed only along or near the Fall Zone, which extends from Washington through Fredericksburg, Richmond, and Petersburg to Emporia, but Miocene strata crop out throughout most of the Coastal Plain except in the area bordering Chesapeake Bay, where they are concealed by Quaternary deposits. The work includes a detailed description of the lithologic character, distribution, and faunal content of the sediments. Upper Cretaceous deposits were not found in the study of outcrops and no Coastal Plain formations other than those mentioned by Darton were described.

Sanford,[5] at about this same time, published on the groundwater resources of the Coastal Plain of Virginia, and, although containing much valuable hydrologic data, the paper did not add greatly to the geologic picture. Other papers, including short publications by the writer, have presented information on either the surface or subsurface geology of the Virginia Coastal Plain but did not appreciably alter the previously established basic ideas of Coastal Plain geology.

OUTLINE OF SUBSURFACE GEOLOGY

BASEMENT ROCK

The Coastal Plain sediments lie above the bedrock; they thin to a feather edge along the Fall Zone extending through Richmond, Petersburg, and Emporia, and thicken eastward. Bedrock has been reached in several wells along and near the Fall Zone but in only a few wells in the area on the east. At Fort Monroe bedrock was reached at 2,246 feet; it was not reached at 1,760 feet at Norfolk waterworks; in 1928 an oil-prospecting well at Mathews reached bedrock at a depth of 2,225 feet.

[4] W. B. Clark and B. L. Miller, "The Physiography and Geology of the Coastal Plain Province of Virginia," *Virginia Geol. Survey Bull.* 5 (1912), pp. 46–223.

[5] Samuel S. Sanford, "The Underground Water Resources of the Coastal Plain Province in Virginia," *Virginia Geol. Survey Bull.* 5 (1913), pp. 5–28.

FIG. 1.—Map of Coastal Plain area in Virginia south of Potomac River showing locations of cross sections (Figs. 2–7).

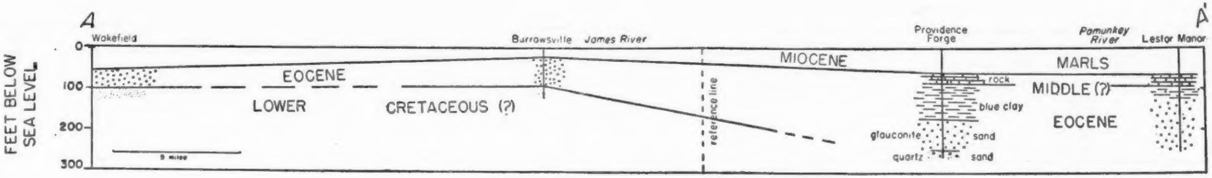

FIG. 2.—Geologic cross section *AA'*.

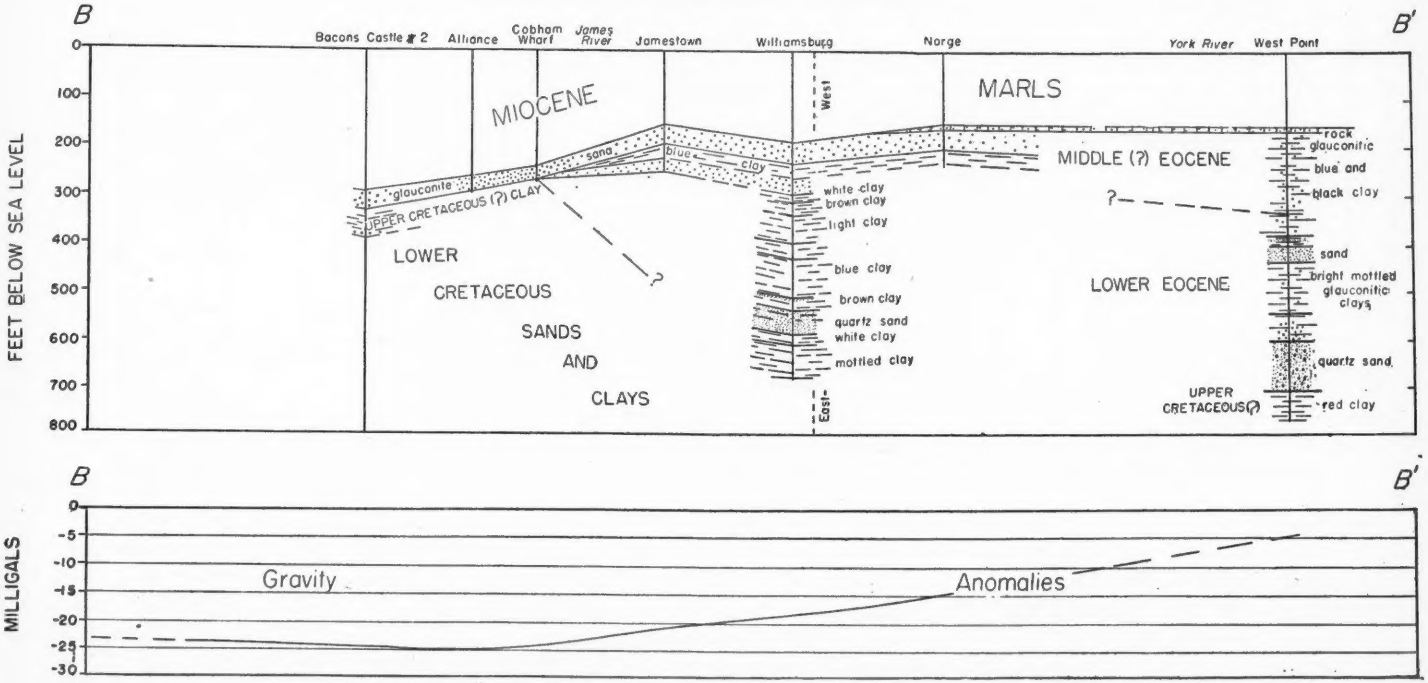

FIG. 3.—Geologic cross section and anomaly curve, section *BB'*.

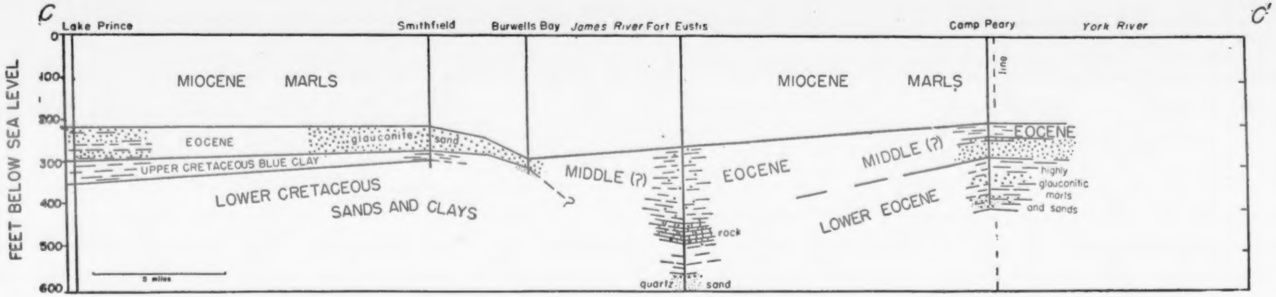

FIG. 4.—Geologic cross section *CC′*.

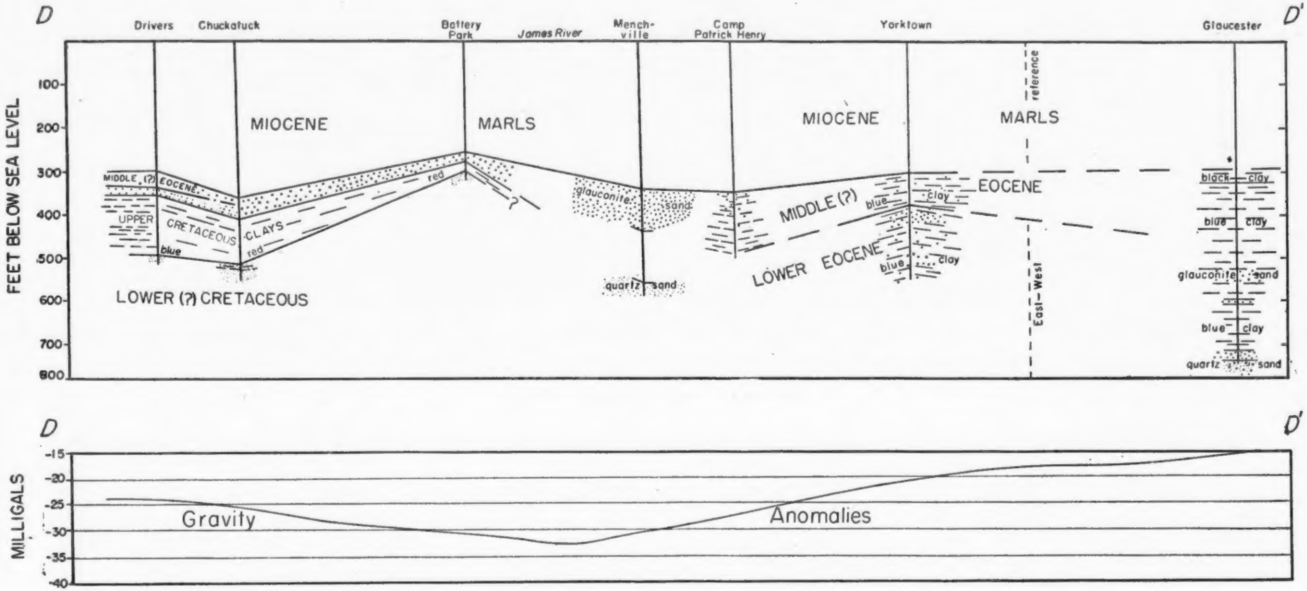

FIG. 5.—Geologic cross section and gravity-anomaly curve, section *DD′*.

FIG. 5.—Geologic cross section and gravity-anomaly curve, section DD'.

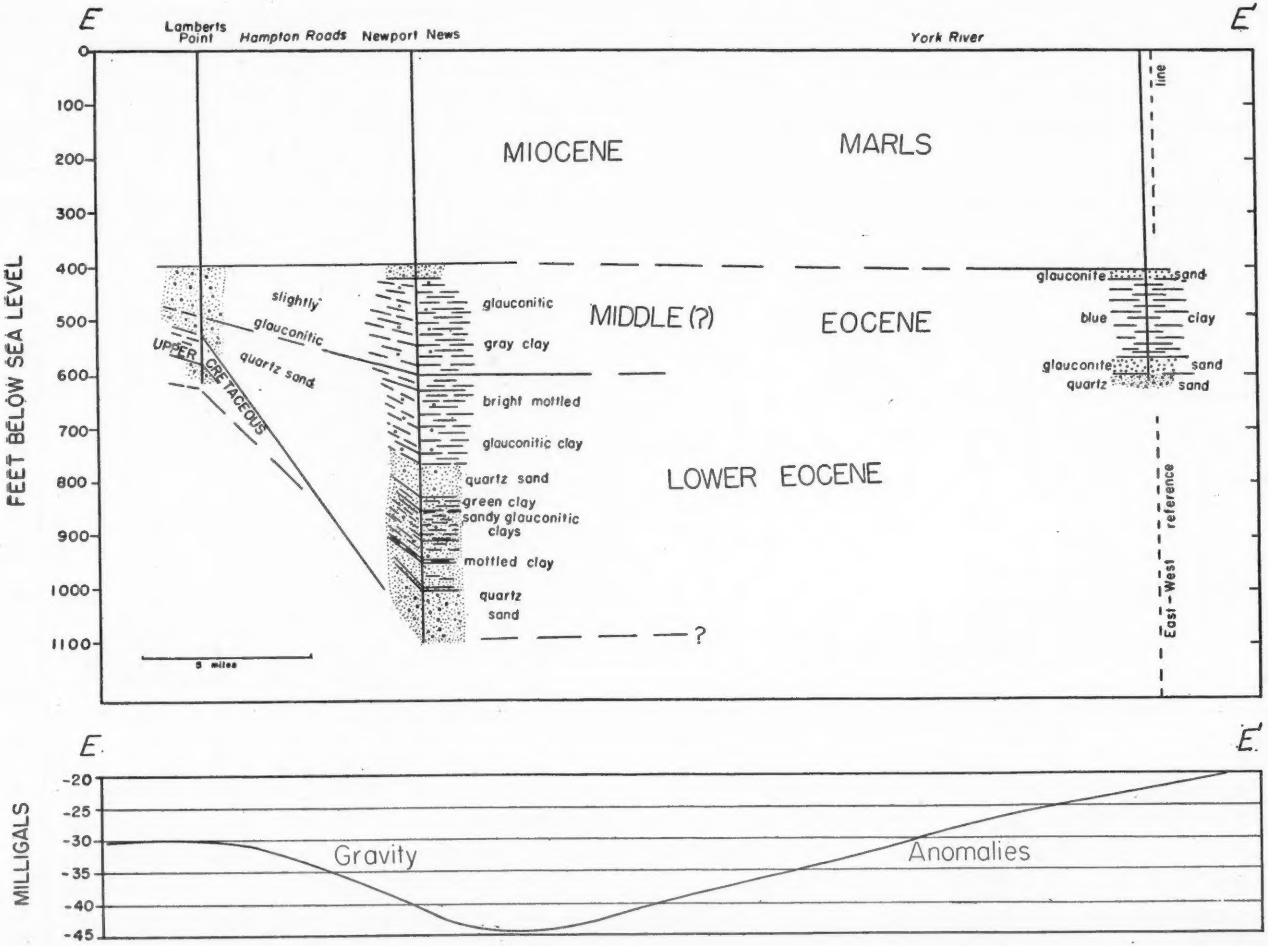

FIG. 6.—Geologic cross section and gravity-anomaly curve, section EE'.

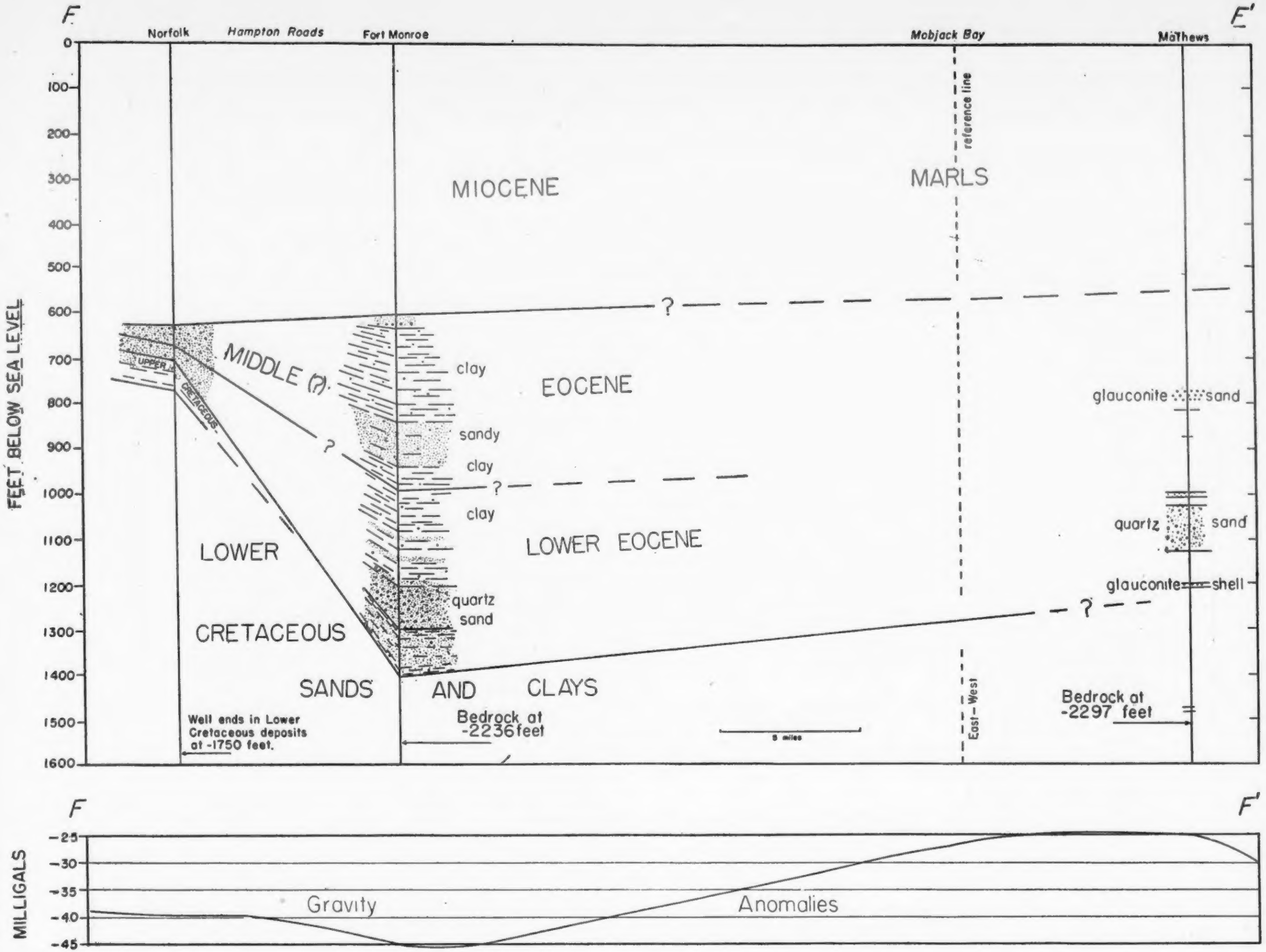

FIG. 7.—Geologic cross section and gravity-anomaly curve, section *FF'*.

In 1937 Ewing, Crary, Rutherford, and Miller[6] published on the results of a geophysical (largely seismic) survey in which a traverse was taken from a point near Petersburg through northern Prince George and Surry counties across the James River to Mulberry Island (near Fort Eustis), Warwick County, and thence to Fort Monroe. Another station was located near Cape Henry and others at sea. In this study the depths to bedrock at points intermediate between Petersburg and Norfolk were determined; it was also found that near Cape Henry the depth to bedrock was about 2,900 feet and near the edge of the continental shelf the Coastal Plain strata attained a thickness of more than 12,000 feet.

The basement rock found by wells near the Fall Zone and at Fort Monroe and Mathews Court House is granitic, as far as is known. Triassic sediments have been encountered at Ashland, Hanover County, along the Fall Zone, and at Bowling Green, Caroline County, also along the Fall Zone.

LOWER CRETACEOUS

The sediments that lie immediately above bedrock, consist largely of unconsolidated clay, sandy clay, and sand, and are assigned to the Potomac group of Lower Cretaceous age. The sand is commonly arkosic. The Potomac group is continental in origin, as evidenced by the abundance of plant material and absence of marine forms, and individual strata vary greatly laterally; beds thicken, thin, and pinch out in short distances and, almost without exception, individual beds can not be traced more than a mile or two at the most. However, the make-up of the Potomac deposits is such that water-bearing sands can generally be expected somewhere within a reasonable depth at almost all localities where this group is reached. Sand beds are generally not more than 30 or 40 feet thick, although exceptions are known; sand makes up one-third to one-half of the total sediments present in most places. In a very few places Potomac sediments consist almost entirely of clay, or almost entirely of sand.

The Potomac group has been considered to thicken to about 1,300 feet at Fort Monroe but recent information indicates that the thickness there (and perhaps also at Mathews) may be only about 800 feet. At the Norfolk waterworks, which is in a location slightly farther seaward than Fort Monroe, the Potomac group is apparently more than 975 feet thick since bedrock was not encountered at 1,760 feet (the total depth of the well) but, as discussed later, bedrock may lie a short distance below.

Although both the Patuxent and Patapsco formations are present in Virginia, the upper of the two, the Patapsco, does not crop out south of Fort Belvoir, Fairfax County, and is assumed to be absent in the south part of the area. The

[6] Maurice Ewing, A. B. Crary, H. M. Rutherford, and Benjamin Miller, "Geophysical Investigations in the Emerged and Submerged Atlantic Coastal Plain," *Bull. Geol. Soc. America*, Vol. 48 (1937), p. 790.

Lower Cretaceous sediments are therefore classed as Potomac group, undifferentiated.

South of the James River the Potomac group yields copious supplies of water. North of the James River most wells apparently do not reach the Potomac group.

UPPER CRETACEOUS

Upper Cretaceous sediments, clays and sands containing a little glauconite, and, commonly "rock" layers, were described from two deep wells at Norfolk by Darton. They are about 75 feet thick. Sediments from the Norfolk wells were re-examined in this office within the last few months and foraminifers separated and submitted to Cushman for determination. The boundaries were essentially unchanged as a result of this restudy and remain about as Darton had shown them (Fig. 7, sec. *FF'*). However, Upper Cretaceous fossils were not found in cuttings from the old Fort Monroe wells nor were they present in a well at the Newport News gas works, drilled in 1944, which reached a depth of 1,082 feet. Hence, these strata are assumed to be absent in the lower end of the York-James Peninsula and it seems likely that they were removed by erosion in pre-Eocene time.

Recently it has been found that Upper Cretaceous sediments extend westward through Norfolk County as far inland as Franklin, Southampton County. The writer tentatively correlates these strata with other strata described in drillers' logs throughout the large part of the area south of the James River, in particular, a widely distributed red clay stratum which possibly marks a near-shore phase of an Upper Cretaceous sea. Elsewhere variegated Upper Cretaceous (?) sediments are interbedded with blue fossiliferous marls of a marine aspect.

North of the James River practically nothing is known of the Upper Cretaceous sediments although the red clay penetrated at 721 feet at West Point (Fig. 3, sec. *BB'*) is suggestive of the Upper Cretaceous (?) red clay south of James River.

EOCENE

Although the Pamunkey group of Eocene age crops out along the Fall Zone in many places, the section along the Potomac River from the mouth of Potomac Creek to Mathias Point is probably by far the best in Virginia. The lower member of the Pamunkey group, the Aquia formation, is correlated with the lower part of the Wilcox[7] in the standard section. The correlation has been recently confirmed on the basis of the foraminiferal content.[8]

The Nanjemoy formation is made up of the Patapsco clay member and the Woodstock greensand marl member; the Patapsco is correlated with the upper

[7] C. Wythe Cooke, Julia Gardner, and Wendell P. Woodring, "Correlation of the Cenozoic Formations of the Atlantic and Gulf Coastal Plain and the Caribbean Region," *Bull. Geol. Soc. America*, Vol. 54 (1943), Chart 12.

[8] J. A. Cushman, "Foraminifera from the Aquia Formation in Virginia," *Contrib. Cushman Lab. Foraminiferal Research*, Vol. 20 (1944), pp. 17–28.

part of the Wilcox and the Woodstock with the upper part of the Claiborne.[9]

According to Cushman, the foraminifers occurring below the Nanjemoy are not identical with those found in the material collected from typical Aquia outcrops[10] and the subsurface material may be older Eocene than the Aquia or may even be Paleocene in age. At this point attention may be called to the fossil collected at Franklin which has been designated as "suggestive" of the Midway.[11] However, L. W. Stephenson has recently brought to the writer's attention the occurrence of typical Eocene macrofossils, *Eupsammia conradi* Vaughan and *Ostrea sellaeformis* Conrad ?, in samples which had been collected at 1,440 feet at Fort Monroe. It would seem, then, that the presence of Paleocene deposits is definitely questionable; the sediments below the Nanjemoy are accordingly assigned to the Aquia in this report pending more concrete evidence to the contrary.

The higher Eocene sediments contain many blue glauconitic marl beds and dark glauconite-quartz sands. Considerable variation is present in the make-up of the Eocene from place to place, the presence of glauconite is diagnostic only where it is present in abundance. The presence of small amounts of glauconite in clays or quartz sands may not be reported in drillers' logs and may even be overlooked by geologists if samples are not washed and examined under the microscope.

Mottled glauconitic clays seem to characterize the lower Eocene deposits in Virginia; some are dark whereas others are brightly colored and may be reported by drillers as pink, red, or "rainbow" clay. Below the mottled clays thick permeable quartz sands containing only very little glauconite are commonly interbedded with clayey sediments, particularly north of York River. "Rock" layers (thick shell layers cemented by calcite) are commonly present in the lower Eocene but seeming less common in middle Eocene sediments.

Drill cuttings from the old deep wells at Fort Monroe available to previous investigators were not as characteristic lithologically as at Norfolk and were almost barren of macrofossils below the Miocene. As a result the placement of geologic boundaries at Fort Monroe seems to have been greatly influenced by the record at Norfolk. Sets of samples from the old deep wells at Fort Monroe were restudied in this laboratory and it was found that washed residues were fairly diagnostic of the formations penetrated. Highly glauconitic residues first appeared at about 600 feet and as much as 2 or 3 per cent of glauconite persisted in the samples down to 1,440 feet; only slight traces of glauconite were present from 1,440 to 1,540 feet and no glauconite was present in samples from greater depths. Cushman subsequently found that Eocene foraminifers were present from 604 to 1,440 feet; in addition, as already noted, Eocene macrofossils have

[9] C. Wythe Cooke, Julia Gardner, and Wendell P. Woodring, *op. cit.*

[10] J. A. Cushman, *op. cit.*

[11] Horace G. Richards, "Macrofossils from Wells on the Atlantic Coastal Plain," *Bull. Geol. Soc. America*, Vol. 54 (1943), p. 1826.

been determined from material collected at 1,440 feet; thus the lower boundary of the Eocene at Fort Monroe is about 725 feet lower than its position at the Norfolk city waterworks or about 700 feet lower than where the base of the Eocene was placed by early investigators.

The thickening of the Eocene deposits from Norfolk city waterworks to Fort Monroe is from about 75 feet to more than 800 feet. As shown in the cross sections (Fig. 6, sec. *EE′* and Fig. 7, sec. *FF′*), greater thickening occurs in the lower Eocene than in the middle Eocene.

It has been found that the Eocene deposits are characteristically much thicker north of the James River than south of that river. At Fort Eustis, Camp Patrick Henry, Yorktown, Williamsburg, West Point (Fig. 2), and Walkerton these sediments are hundreds of feet thick; south of the James River they are characteristically less than 100 feet thick. Less is known of the minimum thickness of Eocene deposits in the western part of the Coastal Plain (Charles City, Henrico, and New Kent counties) but the available data seem to show conclusively that the relationship established in the Hampton Roads area persists to some degree almost to the Fall zone.

MIOCENE

The Chesapeake group of sediments of Miocene age include, in ascending order, the Calvert, Choptank, St. Marys, and Yorktown formations. Of these the Choptank is recognized only in northern Virginia. The Miocene formations overlap the older Coastal Plain sediments and may rest directly on sediments of the Potomac group or even on granitic bedrock, as along the Fall Zone. Where the total thickness of Miocene sediments ranges up to 200 or 300 feet, as at Bacons Castle in Surry County, Lake Prince in Nansemond County, and at Camp Peary and Yorktown in York County, three lithologic units are generally represented: (1) a lower zone of sandy clay in which a moderate amount of shell is present, (2) an intermediate zone of blue unfossiliferous tough clay, and (3) an upper zone of permeable sands and shell strata interbedded with thin impermeable clay strata. The three units may correspond with the Calvert, St. Marys, and Yorktown formations.

In this paper the Miocene is treated as a unit.

PLEISTOCENE

Coastal Plain sediments are everywhere veneered by gently seaward sloping terrace deposits composed of clay and sand. The higher terraces are probably continental in origin whereas the lower ones are marine in origin. The terrace deposits may reach a thickness more than 50 feet in places along the Fall Zone but on the east they are generally less than 30 feet thick. In the river banks and throughout the larger part of the area older sediments are exposed beneath the terraces but throughout the area bordering Chesapeake Bay where the terraces extend below sea-level the older formations are not exposed.

STRUCTURE

The Coastal Plain sediments dip gently seaward and, lacking information to the contrary, it has generally been assumed that only gentle structures, if any, were present.

A structural high in the granitic basement rock at Cape Fear, North Carolina, has been recognized and described[12] and the possible presence of faults in the basement rock have been mentioned by Stephenson[13] who suggested that the Charleston earthquake may have been caused by movement along an old fault. McCarthy,[14] as a result of a study of magnetic anomalies in North Carolina noted that a series of disturbed zones appears to be present parallel with the trend of the Appalachians. In 1940 Woollard[15] noted strong magnetic anomalies in the James River area in the Coastal Plain of Virginia but tended to ascribe most of these to differences in composition of the basement rock rather than to structure since Ewing's[16] seismic determinations had tended to show that the landward part of the seaward bedrock slope was relatively uniform. Swick[17] in 1940 made a number of gravity determinations in Virginia and adjacent North Carolina: the anomalies recorded have been considered largely due to deep-seated causes.[18]

In 1939 the writer[19] published a short paper showing the presence of a monocline in the Coastal Plain at Franklin, Southampton County, by which sediments there descend 40 feet toward the east in less than ½ mile. The geologic cross section accompanying the paper showed a basinal structure in southwestern Southampton County, a very gentle dome at Newsoms in southern Southampton County, and a small reversal of dip at Waverly in northeastern Sussex County. Reverse faults of small throw that are exposed in unconsolidated sediments

[12] L. W. Stephenson, "Major Features in the Geology of the Atlantic and Gulf Coastal Plains," *Jour. Washington Acad. Sci.*, Vol. 16 (1926), No. 17, Pl. 1 facing p. 466.
W. C. Mansfield, "Some Deep Wells near the Atlantic Coast in Virginia and the Carolinas," *U. S. Geol. Survey Prof. Paper 186-I* (1937), pp. 159–61.

[13] L. W. Stephenson, "Structural Features of the Atlantic and Gulf Coastal Plain," *Bull. Geol. Soc. America*, Vol. 39 (1928), p. 893.

[14] Gerald R. McCarthy, "Magnetic Anomalies and Geologic Structures of the Carolina Coastal Plain," *Jour. Geol.*, Vol. 44 (1936), p. 405.

[15] George P. Woollard, "A Comparison of Magnetic, Seismic, and Gravitational Profiles on Three Traverses across the Atlantic Coastal Plain," *Trans. Amer. Geophysical Union*, Part II (1940), pp. 301–09.

[16] Maurice Ewing, A. B. Crary, H. M. Rutherford, and Benjamin Miller, "Geophysical Investigations in the Emerged and Submerged Atlantic Coastal Plain," *Bull. Geol. Soc. America*, Vol. 48 (1937), p. 790.

[17] C. H. Swick, "Gravitational Determination of Deep-Seated Crustal Structure of Continental Borders (Observations and Methods)," *Trans. Amer. Geophysical Union*, Pt. III (1940), pp. 801–08.

[18] G. P. Woollard, "Gravitational Determination of Deep-Seated Crustal Structure of Continental Borders (Structural Interpretation of Gravity Observations)," *Trans. Amer. Geophysical Union*, Pt. III (1940), pp. 808–15.

[19] D. J. Cederstrom, "Geology and Artesian Water Resources of a Part of the Southern Virginia Coastal Plain," *Virginia Geol. Survey Bull. 51-E* (1939), p. 129.

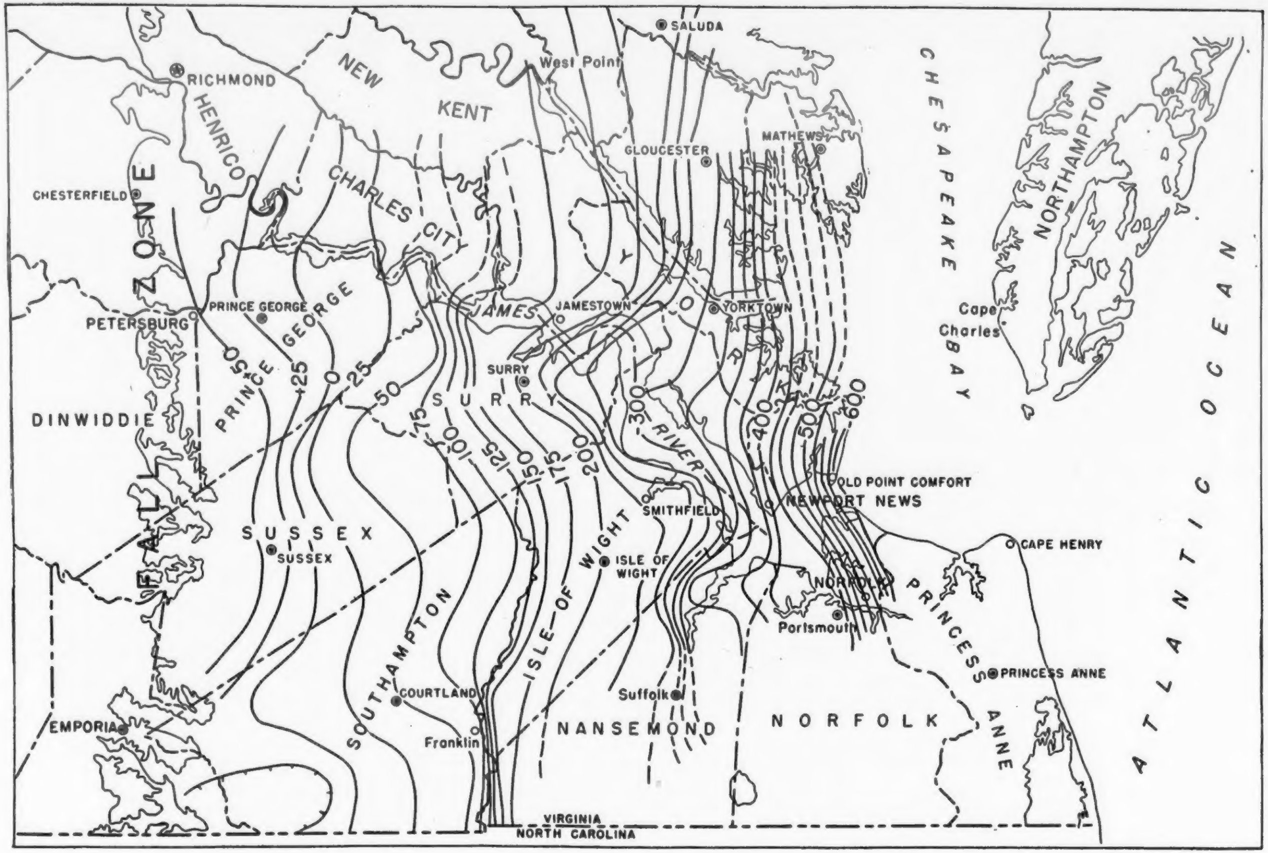

FIG. 8.—Structural contour map of southeastern Virginia drawn on Eocene-Miocene contact. Datum is sea-level.

along the Fall Zone at Triangle, near Quantico in northeastern Virginia, and at Drewrys Bluff, near Richmond, were mentioned. The statement was made that structures shown in the cross sections of the southeastern Virginia Coastal Plain are of interest in that they indicate not only that movements in Cretaceous, Tertiary and Pleistocene took place as uplifts or depressions of large portions of the coastal area but also that these uplifts were accompanied by faulting of the crystaline basement rocks. This faulting was then transmitted upward as faults or folds, or both.

STRUCTURAL GEOLOGY OF JAMES RIVER-HAMPTON ROADS AREA

SUMMARY

When the thicknesses of Eocene sediments on either side of James River and Hampton Roads are considered (Fig. 2), it is apparent that either subsidence occurred in the area north of the river in pre-Eocene time, allowing a much greater thickness of Eocene sediments to accumulate there than in the area on the south, or the pre-Eocene surface was deeply channelled with the same result.

The short distance in which thickening occurs, the apparent uniform thickness of the Eocene sediments in the whole Virginia Coastal Plain north of James River and Hampton Roads, and the progressive decrease in thickening upward seem to indicate that a basin formed in pre-Eocene time, probably by faulting action. The area continued to subside throughout Eocene time, but at a decreasing rate and at the close of Eocene time, subsidence appears to have ended. The results of gravity survey of the area (Fig. 9) show that a marked break extends up the James River; this, in connection with data in the adjacent areas, is interpreted by the writer to favor the existence of a basement rock fault rather than some other feature.

The apparent absence of Upper Cretaceous sediments at Fort Monroe and Newport News and the thicker section of Potomac sediments at Norfolk, point to post-Upper Cretaceous channeling of the Fort Monroe-Newport News area. The greatest possible difference in depth to bedrock between Norfolk and Fort Monroe is less than 500 feet; hence, if the surface of the granitic rock was horizontal before faulting, the maximum subsidence due to faulting must likewise be less than 500 feet. The increase in thickness of Eocene sediments is about 700 feet and hence a minimum of 200 feet of these sediments north of Hampton Roads must have been laid down in a post-Upper Cretaceous channel according to this line of reasoning.

On the other hand, the Norfolk waterworks well lies about 6 miles seaward of Fort Monroe. If the Norfolk waterworks record were compared with a section 6 miles east of Fort Monroe, it might be found that the Eocene sediments were only slightly thicker than at Fort Monroe but depth to basement rock was several hundred feet greater, and that a greater possible difference in depth to bedrock exists than between Norfolk waterworks and Fort Monroe.

Likewise, if the surface of the granitic bedrock sloped southward in pre-

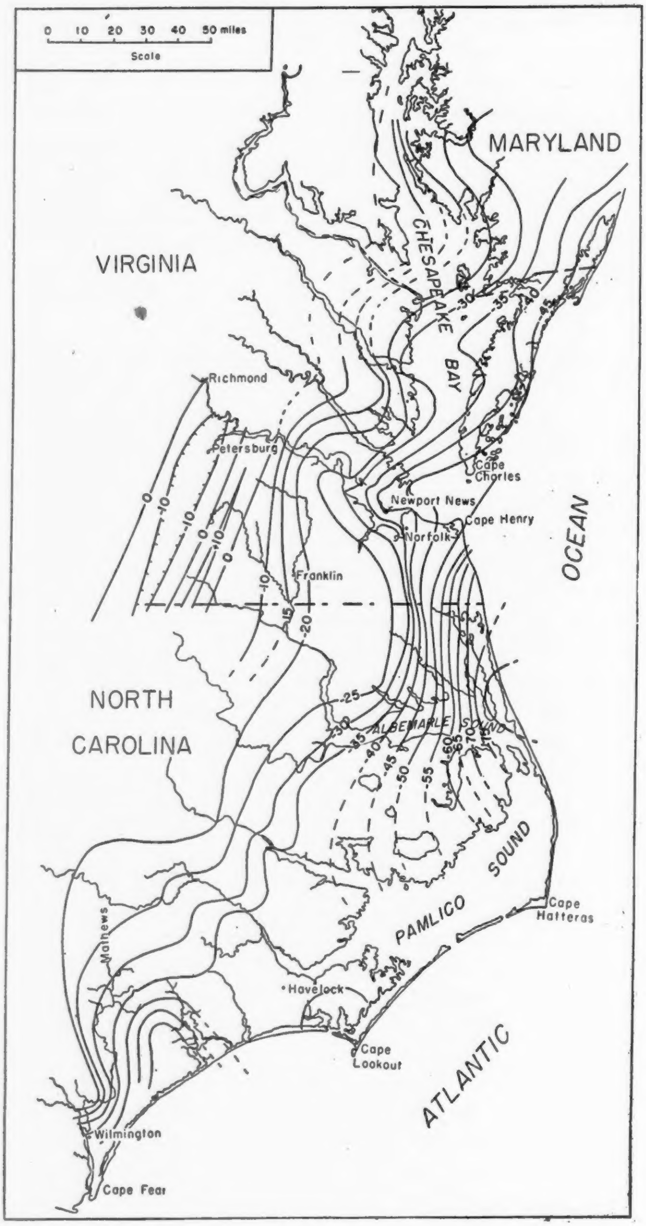

FIG. 9.—Map showing contours on gravity anomalies in southern Maryland, Virginia, and North Carolina. Contour interval, 5 milligals below −10 and 10 milligals above −10. Replotted from data by Swick, *Trans. Amer. Geophysical Union*, Pt. III (1940), pp. 801–08.

Eocene time, then a displacement of 650 feet on the downthrown side (northern) of the fault might result in only a few hundred feet difference in actual depth below sea-level. Hence, too much emphasis must not be placed on what at first appears to be a limiting factor on the amount of vertical displacement which has occurred along the fault.

A period of gentle folding occurred in post-Miocene time (Fig. 8).

DETAILED DESCRIPTION

The data on which a major part of the structural history is based is shown in Figure 6, section *EE′* and Figure 7, section *FF′*. As already noted, in the Norfolk waterworks well (sec. *FF′*), almost 1,000 feet of Potomac sediments had been penetrated when the well was abandoned at 1,760 feet. At Fort Monroe, according to recent data, the Potomac group may be less than 800 feet thick.

Upper Cretaceous strata were proved to be present in both the waterworks and Lamberts Point wells at Norfolk but they have not been found at either Fort Monroe or Newport News. Aside from a lack of microfossil evidence, it seems unlikely that a shelly *Exogyra* zone would have been passed without recognition.

The thinning of the Potomac sediments and absence of Upper Cretaceous sediments north of Hampton Roads can probably be best explained as having resulted from differential erosion of that area in post-Upper Cretaceous time. Seemingly a minimum of a 250 feet (175+feet of Potomac and 75 feet of Upper Cretaceous) of sediments now present at Norfolk were removed at that time.

The Eocene strata shown in section *FF′* thicken from about 75 to about 800 feet; in section *EE′*, 125 feet of Eocene strata at Lamberts Point thickens to about 560 feet. At Newport News Eocene foraminifers are present to a depth of 965 feet and a little glauconite is found to a depth of 968 feet; it is probable that the Eocene extends to this depth at least. From 968 to 1,082 feet sediments were predominantly sandy and contained only a trace of glauconite and only a few Miocene and Eocene foraminifers, washed down from above. However, it is entirely possible that the sandy strata down to a depth of 1,082 feet are basal Eocene sands and the total thickness of Eocene sediments approaches 700 feet.

At Fort Monroe and Lamberts Point, samples submitted to J. A. Cushman did not permit differentiation of the lower and middle Eocene sediments. At the Norfolk waterworks the foraminifers and insoluble residues indicate middle Eocene strata are about 45 feet thick and lower Eocene strata 30 feet thick. At Newport News the middle Eocene strata are about half as thick as the lower Eocene deposits.

Although a pre-Eocene channel in the Newport News-Fort Monroe area may have accounted for some of the northward thickening of the Eocene formations, it is difficult to see how both higher and lower formations could thicken; it is believed therefore that a fault passes through Hampton Roads along which movement took place in Eocene time; Fort Monroe and Newport News are on

the downthrown side of this fault. The amount of displacement along the fault is a matter of speculation since depth to bedrock at Norfolk is not known. Bedrock was not encountered at 1,760 feet, hence, the greatest possible difference between depth to bedrock at Norfolk and Fort Monroe, where it was reached at 2,246 feet, is less than 500 feet. However, if the pre-fault basement surface sloped toward the south, the original difference in elevations at that time must be added to the possible maximum of 500 feet displacement. Further, depth to bedrock at Fort Monroe is not necessarily comparable with depth to bedrock at Norfolk waterworks, if it is assumed that the fault has an east-west or northwest-southeast trend; Fort Monroe is 6 miles farther inland. Depths to bedrock at a point 6 miles east of Fort Monroe might well be several hundred feet deeper, whereas the thickening of Eocene sediments might not be as great; here, again, a few hundred feet of possible displacement should be added to the possible maximum.

It seems possible, therefore, that all the thickening could be accounted for by subsidence due to faulting. However, about 250 feet of Upper Cretaceous and Potomac sediments are lacking at Fort Monroe and the possibility that these were removed by pre-Eocene channeling should be kept in mind.

The progressive upward decrease in thickening of Eocene deposits has been cited as a reason for postulating an infaulted basin. Further, if the topography of the present Coastal Plain can be considered to be a guide to the past, the improbability of 650-foot canyons in soft unconsolidated sediments seems great and, in fact, channels 250 feet deep are not too easily visualized. However, some channeling must be postulated unless differential uplift occurred between the end of the Upper Cretaceous and the beginning of Eocene deposition in the area north of James River. Further data may show that the thickest of the Eocene deposits north of the James River are not localized in channels, in which case a pre-Eocene uplift must be introduced into the picture.

Movement along the fault began in Eocene time and as sediments accumulated, small movements occurred as a result of which the area on the downthrown side deepened and allowed a much greater thickness of Eocene deposits to be deposited there, as compared with the area on the south. Although a fault may be present in the basement rock it does not necessarily follow that the overlying unconsolidated sediments are faulted to the same degree. The fault may be transmitted upward into Coastal Plain sediments as such but beyond a certain point it may pass upward into a sharp fold.

In the Hampton Roads area the Miocene boundaries, as shown in section *EE'* and *FF'*, are apparently unaffected and it seems that movement along the fault ceased before Miocene time began. However, where true north-south sections are taken it is seen that the Eocene-Miocene contact is about 200 feet lower at Fort Monroe than at Lamberts Point, directly south. The difference in position of the contact between northern Nansemond County and Newport News may be less than 100 feet. Eocene-Miocene boundaries in other sections

(Figs. 2–5) are also seen to be warped. Whether this movement is related to the earlier faulting is not yet certain. In this connection, attention may be pointed to a reverse fault of small throw in Washington, D. C.,[20] along which movement of the basement rock is transmitted upward into overlying Pleistocene gravels.

The direction and continuation of the Hampton Roads fault is a matter of considerable interest. It is obvious that both Newport News and Fort Monroe lie north of the fault on the downthrown side, and Lamberts Point and the Norfolk city waterworks lie south of the fault. Ewing's data indicate that basement rock lies at 2,600 feet near Cape Henry and it seems then that this point, too, lies north of the fault. Thus the Hampton Roads fault seemingly extends more or less east and west and passes south of Newport News and Cape Henry.

Several cross sections have been drawn to bring out the westward continuation of the Hampton Roads fault. These sections, which have been taken almost directly north and south (Fig. 1), show that marked thickening of the Eocene sediment occurs in all the lower York-James Peninsula and that the thickened section may everywhere extend as far south as James River. The thickening occurs as far west as central Charles City County (Providence Forge, Figure 2, section *AA′*); samples from a well at Malvern Hill, in western Charles City County, indicate that there the Eocene may extend to at least 150 feet below sea-level. Unfortunately, samples available were not properly labeled but it does seem evident that at Malvern Hill Eocene sediments are definitely thicker than at Hopewell, a short distance south.

The geologic boundaries at Providence Forge and Lester Manor (sec. *AA′*), Bacons Castle, Jamestown and West Point (sec. *BB′*), Lake Prince, Fort Eustis and Camp Peary (sec. *CC′*), Drivers, Camp Patrick Henry and Yorktown (sec. *DD′*), Newport News (sec. *EE′*) and Norfolk, Fort Monroe and Mathews (sec. *FF′*), have been drawn on the basis of studies of insoluble residues and foraminiferal content of well cuttings. Most of the suites of samples at hand are complete or almost complete. At other locations the boundaries have been drawn on the basis of drillers' logs; in most places where this type of information is used, logs of other wells in the vicinity are also available and the boundaries drawn are believed to be accurate within reasonable limits. The generalized description of the sediments present is shown on the cross sections where drillers' logs are used; it is seen that much reliance is placed on the presence of highly glauconitic sands, as at Cobham Wharf, Hopewell, Lester Manor, Mathews, and Severn. At Williamsburg, the presence of mottled clays and data on thick Eocene beds at near-by Yorktown seem to justify assigning the sediments below the glauconite beds to the Eocene.

The desirability of more detail at some localities is apparent, however. In

[20] N. H. Darton, "Gravel and Sand Deposits of Eastern Maryland," *U. S. Geol. Survey Bull. 906-A* (1939), Pl. 3.

particular, suites of cuttings from deeper wells at Burrowsville (sec. *AA'*), Williamsburg and Cobham Wharf (sec. *BB'*) and Menchville (sec. *DD'*) would give sharper definition of the Eocene basin. More data on wells in the vicinity of Gloucester (sec. *EE'*), Severn (sec. *EE'*), and Mathews (sec. *FF'*) would confirm the character of the Eocene basin north of the York River. It is not certain that the full thickness of Eocene sediments has been penetrated at any place shown in the cross sections in the area north of the James River considered in this paper except at Fort Monroe and Mathews, although the base may have been reached and passed at Newport News and West Point.

It is of interest to note that, as far as data are available and can be interpreted, the Eocene sediments north of the York-James Peninsula maintain their thickness. At West Point, the full (?) thickness is about 500 feet; at Mathews glauconitic strata (largely Eocene?) range through 450 feet of section; the full thickness of Eocene may be considerably greater. At Walkerton, King and Queen County, Eocene sediments seem to be at least 300 feet thick.

At the town of Cape Charles, on the Eastern Shore, a log of an old well which reached a depth of 1,810 feet suggests that Eocene deposits may extend from 890 to 1,680 feet at least. "Green clay with black specks" from 890 to 950 feet, "mixed brown and gray sand and clay" from 1,250 to 1,270 feet, "clay, gravel and sand of many colors" from 1,331 to 1,585, and "pale pink sandy clay" from 1,607 to 1,680 feet seem more likely to be glauconitic and mottled Eocene strata than deposits of some other age. The Eocene-Miocene boundary might be well above 890 feet; the "reddish brown sticky clay" from 1,740 to 1,810 may correspond with the red clay of Upper Cretaceous (?) age reached at 721 feet at West Point (Fig. 3, sec. *BB'*). However, even if strata from 890 to 1,680 feet comprise all the Eocene deposits, the thickness is more than 800 feet.

At Oak Grove, Westmoreland County, north of the Rappahannock River and about 25 miles east of the Fall Zone (Fig. 1), the Eocene is 300 feet thick at the minimum. At Dahlgren, King George County, on Potomac River, about as far east of the Fall Zone as Oak Grove, Eocene sediments seem to extend from sea-level to at least 500 feet below sea-level. Other incomplete data on wells in various localities show that the Eocene is probably equally thick throughout the area.

As already noted, a basin formed in early Eocene or pre-Eocene time and allowed excessive thicknesses to be accumulated, after which deepening of the basin seemed to cease. Erosion took place in the interval between Eocene and Miocene time and the surface on which Miocene sediments were deposited was essentially flat.

However, it will be noted that in sections *AA'* and *DD'* that the base of the Miocene, taken in north-south cross section, is gently but definitely warped and discrepancies in position of the Eocene-Miocene contact in the Hampton Roads area has already been mentioned. In section *DD'*, folding seems to be pronounced from Drivers northward across James River to Menchville. The folding may be or may not be present in the area covered by section *CC'* from Lake Prince to Fort Eustis; data are scanty but those that are available indicate that some

folding is present and greater folding could be present. In section *CC′*, Camp Peary apparently marks a low anticline; in section *BB′* Jamestown apparently is on the axis of a low anticline and Burrowsville (sec. *AA′*) is similarly located.

Warping of the Eocene-Miocene boundary shows that the Coastal Plain sediments underwent a period of mild disturbance in post-Eocene time. The structural contour map on the base of the Miocene (Fig. 8) brings out more details of the warping and covers a larger area than shown in the cross sections. When the structural contour map and cross sections are considered, it should be borne in mind that the Eocene-Miocene boundary is not everywhere accurately determinable from drillers' logs; if the highest Eocene beds are non-glauconitic, the boundary may be drawn too low. Hence, it is again emphasized that an accurate geological picture of the Virginia Coastal Plain will be gained only by patiently collecting suites of samples from wells which will be drilled from time to time and that this paper simply presents the data available, neither implying accuracy of detail nor suggesting that all the events in the geological history of this province are represented.

Since the gentle folds seemingly trend east and west and since the sharpest folds, insofar as present data show, are localized along the James River, it is likely that the post-Miocene folding is genetically related to the faults (or series of faults) which created the Eocene basin. The true nature of the faulting movements creating folds in the overlying Miocene sediments can only be surmised. It is thought that compressional forces in the Coastal Plain cover might have originated from the settling of large segments of the basement rock rather than that deep-seated compressional forces were effective at this late date. Rather marked disturbances would occur along the Hampton Roads fault but movements of basement blocks in the relatively stable (?) area outside this zone would be less intense.

The foregoing paragraphs have been devoted to a discussion of an area in which many details of geology are at hand. Only a little may be said of the geology of the Coastal Plain in northern Virginia; as already noted, the Eocene there is hundreds of feet thick and maintains about the same elevation as in the York-James Peninsula. At Mathews Court House basement rock is found at about the same depth as at Fort Monroe but whether the basement rock surface is relatively uniform between these two points is something that is yet to be proved. Gravitational anomalies rise from a very low value at Newport News (−45 milligals) to a rather high value (−25 milligals) at Mathews (Fig. 9). Why this should be when the basement rock is at the same depth in both places is hardly more than a matter of speculation at present. The few samples on the Mathews well which are available to the writer seem to indicate that the base of the Eocene may be somewhat higher at Mathews than at Fort Monroe; glauconite is reported at 1,220 feet but is present only as a trace in a sample at 1,335 feet. However, the data are few and the Eocene strata may extend well below 1,200 feet.

Practically nothing is known of the subsurface Virginia Coastal Plain geology

south of Norfolk. However, attention may be called to three logs of wild-cat wells drilled in Currituck County, North Carolina (exact location unknown). The logs report "black sand" at from 205 to 220 feet in well No. 1 (altitude, 2 feet); from 160 to 190 feet in well No. 2 (altitude, 24 feet); and from 187 to 210 feet in well No. 2 (altitude, 3 feet). This is undoubtedly glauconite sand and, in the writer's opinion, it is Eocene in age. Glauconite is present in small amounts in the Miocene of Virginia but is known to be present in more than a trace only at the base of the Miocene. It is thought that the probability of the "black sand" reported in the wells at Currituck being anything other than Eocene is slight.

If the Eocene strata are present at approximately 200 feet below sea-level in Currituck County, then they rise rather sharply southward from Norfolk and are indicative of rather strong post-Miocene movement in the area. The data, however, should not be accepted without confirmation but the implications they suggest should be kept in mind in the event that corroborative data become available.

The Cape Fear uplift is called to mind by the data on southeastern Virginia and it would seem that the Norfolk area is a similar uplift. An important difference is to be noted, however; in the Hampton Roads area a fault is postulated separating high and low areas whereas the Cape Fear region has been considered to be an upwarp.

DISCUSSION OF GEOPHYSICAL SURVEYS

As noted, geophysical investigations in the Coastal Plain of Virginia have been carried out by Ewing, Woollard, and Swick. These include seismic, magnetic, and gravitational surveys. Magnetic traverses have been made along the James River, both on the north and south sides, and one gravitational traverse was made from Emporia, Virginia, south-southeastward to Kittyhawk, North Carolina. The results of these surveys have been interesting but difficult to interpret because the knowledge of the subsurface geology has been and still is meager. Ewing's determinations of depth to bedrock, included in the foregoing discussion, have been very useful but not enough determinations were made to offer much of a clue to the structure of the area as a whole.

In the following paragraphs the writer attempts to interpret to a degree the results of magnetic and gravitational surveys from a strictly empirical point of view. Some of these suggestions are reasonably well based on facts but others are necessarily extremely tentative and must be regarded only as suggestions intended to emphasize the known geology and range of possibilities. It is hoped that this discussion will in some measure stimulate the investigation of the Atlantic Coastal Plain geology by geophysical methods and, what seems more important at this time, the drilling of deep holes in a few places to tie down the observed geophysical data to known geological conditions.

Woollard[21] in 1940 published the results of three magnetic traverses across

[21] George P. Woollard, "A Comparison of Magnetic, Seismic, and Gravitational Profiles across the Atlantic Coastal Plain," *Trans. Amer. Geophysical Union*, Pt. II (1940), pp. 301–09.

the Virginia Coastal Plain. One traverse extended from Richmond through Williamsburg to Newport News and Fort Monroe and a second traverse extended from Centralia, Chesterfield County, through northern Prince George County, parallel with the James River, to Bacons Castle, Smithfield, Portsmouth, Norfolk, Virginia Beach, and northern Princess Anne County. A third short traverse extended from a point near Petersburg to Waverly, Sussex County.

Woollard found that magnetic values were low for a distance of about 15 miles east from the Fall Zone but then rose to high values for a distance of about 5 miles farther east. This inner zone of high anomalies passes south-southeastward through western Charles City County, north-central Prince George County (west of Burrowsville and Brandon), and between Disputanta and Waverly. No explanation based on the known geology of this area is offered to explain this high nor do the data at hand suggest a reason for the zone of low magnetic values of similar trend extending through northern Warwick County (Fort Eustis area) to northern Nansemond and northeastern Isle of Wight counties.

Woollard shows that marked differences in magnetic values exist between the areas north and south of James River, and in particular, in the areas on either side of Hampton Roads. The values for that part of the traverse extending through northern Surry and Isle of Wight counties, south of James River, are on the average about 200 gammas higher than in the corresponding part of the traverse north of the James River. In that part of the traverse extending from Portsmouth to Virginia Beach the magnetic values are approximately 300 gammas higher than that part of the traverse passing through the Newport News-Fort Monroe area.

These data therefore indicate that some geological conditions south of James River are markedly different from those north of James River since the values are consistently higher in the Petersburg-Norfolk traverse. However, irregularities occur in both curves which tend to indicate that zones of magnetic disturbance extend more or less north and south, more or less parallel with the strike of the sediments.

The relatively high values obtained in the traverse south of the James River, as compared with the traverse taken north of the James River along the downthrown side of a fault trending along that river, and the increasing difference in magnetic values in an eastward direction, may indicate that displacement along the fault increases in that direction.

It is of particular interest to note that from Cape Henry to the Norfolk city waterworks all readings were between 400 and 600 gammas although Ewing's work seems to show that basement rock at Cape Henry is about 700 feet deeper than at Fort Monroe where the magnetic values are less than 200 gammas.

Swick,[22] in 1938, presented data on two traverses along which gravity deter-

[22] C. H. Swick, "Gravitational Determination of Deep-Seated Crustal Structure of Continental Borders; Observations and Methods," *Trans. Amer. Geophysical Union*, Pt. III (1940), pp. 801–08.

minations were made. One of the traverses was taken along the line of Ewing's seismic traverse and extended from Amelia County in the Piedmont through Petersburg to Bacons Castle and across the James River to Fort Eustis and Hampton (near Fort Monroe). A number of additional readings were made in the York-James Peninsula up as far as Williamsburg, one at Gloucester Point, and others in Mathews County and on the Eastern Shore, as shown in Figure 9. A second traverse extended from Dinwiddie County (in the Piedmont province), through Emporia (on the Fall zone), and east-southwestward through northeastern North Carolina to Kittyhawk, North Carolina. These data have been replotted on a 5-milligal contour interval (Fig. 9).

A zone of high anomalies along the Fall zone south of Richmond apparently extends south-southwestward into the Piedmont province west of the Fall Zone. These anomalies are seemingly a reflection of Piedmont geology and, as such, do not fall within the scope of this paper. The roughly north-south trend of this zone which extends into the Piedmont province, suggests that magnetic zones of similar trend may be a reflection of differences in bedrock composition rather than differences in thickness or makeup of Coastal Plain sediments.

In general, along the two west-to-east profiles, anomalies fall progressively as the sea is approached but a marked flattening of the slope of the northern profile is noted where that traverse crosses the James River from eastern Surry County to Warwick County; a more marked break in slope is noted in the southerly traverse in Hertford to Gates County in northeastern North Carolina (south of the Courtland-Suffolk area in Virginia). The flattening of the northern gravitational profile covers the area transected by the Hampton Roads fault postulated by the writer. However, it should be noted that a variation occurs in the direction of the northern traverse in the area of flattening which is probably sufficient to explain the observed break. No such variation in the direction of traverse may be called upon to explain the very marked flattening of the profile in northern North Carolina. The writer has no data on the North Carolina area but in the Virginia area immediately on the north rather detailed geology is at hand. At Franklin and South Quay, 8 miles south of Franklin, a monocline is present; the Eocene sediments east of this monocline lie about 40 feet lower than in the area immediately on the west. It is thought that this monocline is caused by movement along a fault along the basement rock which dies out upward as a fold. The fault, if it is a fault, may extend southward into North Carolina and across the traverse made by Swick.

In eastern Virginia and North Carolina the gravity contours, in a very general way, parallel the coast but the variations from normal are many and without much doubt have an important bearing on fundamental Coastal Plain problems if they can be understood.

In Figure 9 it is shown that the -40 milligal contour passes from Cape Charles southwestward, crosses the lower end of the York-James Peninsula above Newport News and then trends sharply eastward and southward around

the eastern side of the city of Norfolk. Additional points show that the −35 and −45 milligal contours have an almost identical trend. The trend of these contours shows that fundamental geologic variations occur in the Hampton Roads area and it is the writer's opinion that the Hampton Roads fault, as postulated, is probably the cause of the observed variation in gravity anomalies. With this thought in mind, it may be seen that the −25 milligal passes southwestward from a point just below Yorktown to central Warwick County (just below Fort Eustis) and then swings sharply westward to eastern Surry County and then trends sharply south-southeastward again to southwestern Norfolk County. The trace of this contour indicates that the zone of disturbance in the Hampton Roads area extends upriver at least as far as Hog Island (northeastern tip of Surry County).

According to Swick's data,anomalies rise northward from the Hampton Roads area and are relatively high in Gloucester and Mathews counties. This is of particular interest because it is known that depth to bedrock is about the same in both areas. The possibility suggests itself that if the re-entrant of the high value negative anomalies into the Hampton Roads area is caused by a fault of several hundred feet displacement, then the re-entrant bordering the Gloucester-Mathews gravitational high on the north may be caused by a similar fault of similar trend.

The −40 milligal contour re-entrant between Havelock and Wilmington in North Carolina marks a zone of disturbance similar to the zone of disturbance extending inland from the Hampton Roads area in Virginia. It seems likely that this re-entrant may also mark a fault, as in the Hampton Roads area, and that the Cape Fear uplift is an uplifted fault block rather than a ridge. However, detailed geophysical data and further deep drilling are necessary here, as in eastern Virginia, before final conclusions may be reached regarding the main geologic events, much less the details.

CONCLUSIONS

The solution of complex problems of Virginia Coastal Plain geology can be attained only when much more subsurface data are at hand. At present, it is planned to devote as much time as is consistent with the purposes for which coöperative studies have been established, to the acquisition of complete suites of well cuttings from deep water wells being drilled in eastern Virginia. This program, even if reasonably well carried out, will not solve all the problems and will probably raise new and important questions. It will be necessary eventually for a number of deep test holes to be drilled to basement rock and for detailed geophysical surveys to be made if the picture is ever to be reasonably complete.

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GEOLOGICAL NOTES

HOLLY FIELD, DE SOTO PARISH, LOUISIANA[1]

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The Holly oil and gas field is located 8 miles north of Mansfield, the Parish seat of De Soto Parish, and 32 miles south of Shreveport. Production is at present confined to Secs. 5 and 6, T. 13 N., R. 13 W., and Secs. 32 and 33, T. 14 N., R. 13 W., embracing approximately 1,000 acres.

The discovery well, R. O. Roy's J. Fuller No. 1, in Sec. 6, T. 13 N., R. 13 W., was completed as a 20 million cubic-foot gas well in September, 1928. The first oil well, R. O. Roy's W. H. Farmer E-1, in Sec. 5, of the same township, was completed in March, 1930, with an initial production of 2,100 barrels of 40° gravity oil.

Early in 1930 the Standard Oil Company of Louisiana acquired Roy's interests at Holly, and during that year drilled 6 oil wells, 3 gas wells, and 13 failures. During 1930 the Arkansas Fuel Oil Company completed one small well, and one failure. A few other failures were drilled outside the developed area, which included Secs. 4, 5, 6, and 8, T. 13 N., R. 13 W., and Secs. 31 and 32, T. 14 N., R. 13 W.

The Standard's oil wells had initial productions ranging from 100 to 3,500 barrels per day; and the gas wells 3, 4, and 15 million cubic feet per day. The depth of the pay sand averaged close to 2,830 feet. Drillers' logs of the early wells do not give accurate figures for sand thicknesses, but these logs show sands ranging from 2 to 20 feet thick.

Melat's Shryver No. 1, located in Sec. 35, T. 14 N., R. 13 W., was completed in 1930 as a 5-barrel producer, and was pumped for a short time.

Production from March, 1930, to November 1, 1943, when 4 wells were still producing oil, was 1,089,255 barrels.

No further development was carried on in this field until 1937, when the Kingston Oil Company completed a small well, located in the NE. $\frac{1}{4}$, NE. $\frac{1}{4}$ of Sec. 32, T. 14 N., R. 13 W. In 1943 H. W. Snowden of Dallas, Texas, acquired leases in Sec. 33 of the same township, and completed several producing wells under the name of the Texas Mineral Lands Company. These wells were later transferred to D. W. Moore of Houston, Texas, who continued drilling under his own name. The Sohio Oil Company has drilled 8 wells, 6 of them oil producers, in Sec. 32, and one gas well in Sec. 6, T. 13 N., R. 13 W. The Texas Mineral Land Company, or successor, has 7 producing wells, the Triangle Drilling Company 2, and J. P. Owens 2, all of which are in Sec. 33. On July 1, 1944, there were 20 wells producing oil, and 3 gas wells, and the field had produced 95,950 additional barrels of oil.

[1] Manuscript received, November 27, 1944.
[2] 3427 Beverly Place.

During the period of early development paleontological study of core sequences from several of the Standard Oil Company's wells showed the presence of Austin chalk above the shale beds inclosing the oil sands. Below the oil sands, limestones and shales of Fredericksburg age were recognized, overlying sands and red shales of Paluxy age. Dark shale cores from the oil-bearing zone were very fossiliferous. L. W. Stephenson of the United States Geological Survey recognized Eagle Ford ammonites in a number of these cores. E. B. Hutson of the Standard Oil Company of Louisiana recognized these shales as Eagle Ford in age, on the basis of the microfauna.

The difficulty of interpreting drillers' logs made it impossible to get an accurate idea of the structural conditions controlling the accumulation of the oil. H. K. Shearer, then with the Standard Oil Company of Louisiana, expressed the opinion that the oil was accumulated in channel sands at the base of the Upper Cretaceous. Recent drilling in the Holly field and adjacent areas has given much additional information through the use of electrical logs, together with cores and cutting records.

A regional subsurface map of the general area (Fig. 1) shows two prominent structural highs, the Sligo-Elm Grove-Caspiana uplift northeast of Holly, and the large De Soto-Red River uplift southeast. These are connected by a low saddle. The Holly field is located on a terrace-nose on the southwest flank of the former uplift. On both of these highs, the Upper Cretaceous Eagle Ford clays rest unconformably on the beveled surface of the Lower Cretaceous Paluxy formation. In the De Soto-Red River field, sands of the Paluxy formation have produced oil and gas. For many years these sands were thought by many people to be the Woodbine sands of East Texas.

The contact of the basal Fredericksburg formation (Walnut clays) with the Paluxy formation (uppermost Trinity) trends northwest and southeast through Caddo Parish and northern De Soto Parish, lying west of the Elm Grove-Caspiana and the De Soto-Red River fields. Westward of this line, the Goodland limestone, and the overlying Washita limestones and shales have been recognized in many wells. The Holly field is just west of the buried Fredericksburg-Paluxy contact.

A southwest-northeast structural section, made with electrical logs, shows that in the Holly field, a channel-like depression was scoured out of the lower Fredericksburg, and filled with sands and shales. It has a maximum depth of about 50 feet, and on this cross section it appears to be about 4 miles long. Insufficient well control makes it impossible to visualize the cross-sectional details in other directions. The trend and size of this channel-like feature can not yet be established.

Where the contact of the Upper and Lower Cretaceous has been cored in the Holly field, a thin bed of cemented gravel has been found, some cores containing carbonized wood fragments. In some wells, this conglomerate rests on the fossiliferous limestones and black shales of the lower Fredericksburg, but in at least

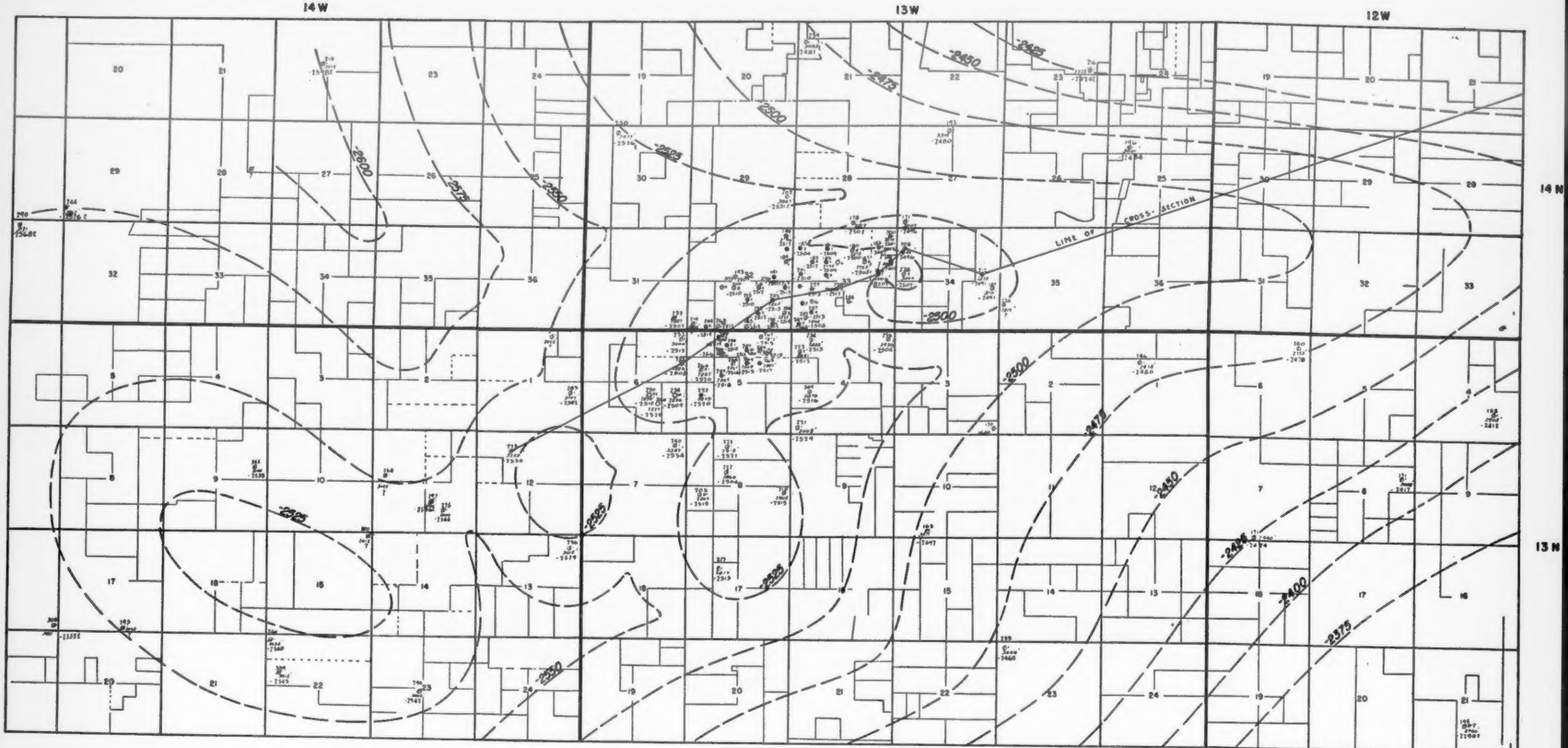

FIG. 1.—Holly oil field and surrounding area, contoured on base of Austin chalk. Contour interval, 25 feet.

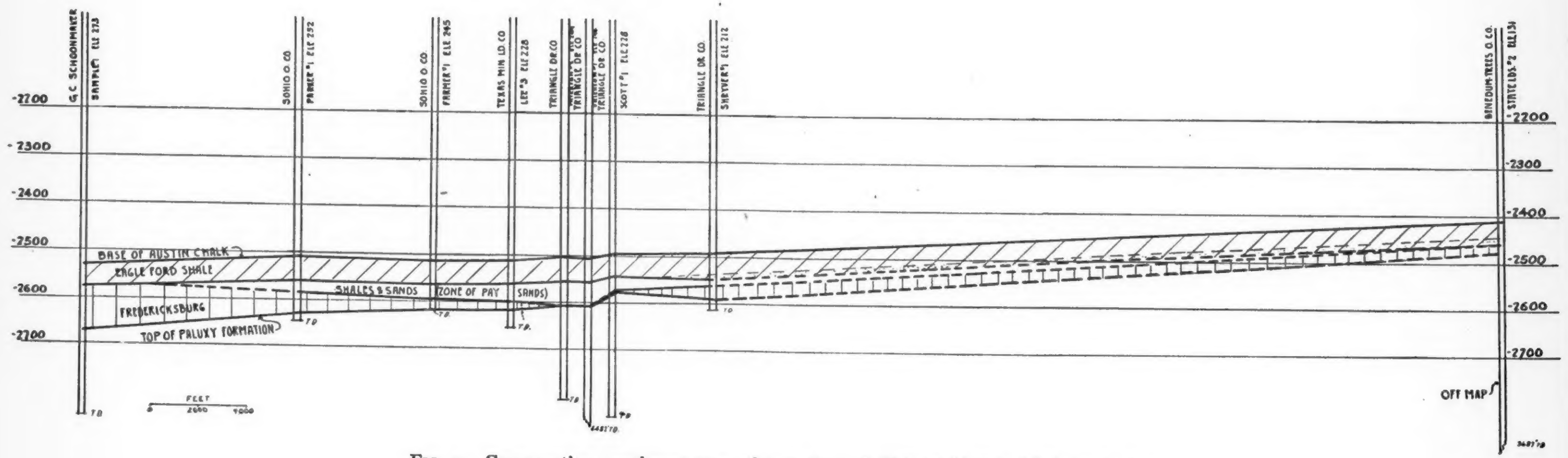

FIG. 2.—Cross section, southwest to northeast, through Holly field. Depths shown in feet.

one well, where the Fredericksburg is completely eroded, its contact is with grayish buff siltstone of Paluxy age. Some of the sands and shales above the basal gravels are bentonitic and tuffaceous.

Production is spotty, as shown by Figure 1. This is caused by the uneven distribution of porous sands. The water level is between sub-sea depths of −2,585 and −2,590 feet.

The beveled surface of the post-Trinity Comanche limestones and shales and the beveled surface of the Paluxy east of the contact limestone previously mentioned are overlain by the Eagle Ford clays, which average about 50 feet in thickness in the vicinity of the Holly field. In the field, these clays overly the slightly older Eagle Ford sands and clays of the channel fill.

APACHE OIL POOL, CADDO COUNTY, OKLAHOMA[1]

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Tulsa, Oklahoma

The Apache pool is located 5 miles northwest of the town of Apache in Ts. 5 and 6 N., R. 12 W., Caddo County, Oklahoma. The Cement pool is 12 miles east, and the outcrop of the Arbuckle limestone on the flank of the Wichita Mountains is 6 miles southwest.

The topography is gently rolling, with elevations varying from 1,300 feet, in the southeast part, to 1,350 feet in the northwest part of the field. There are no topographic features or geologic formations of any particular importance as the Hennessey shale, which is the surface bed, is exposed only for short distances in valley washes in the vicinity.

The Texas Company covered this area with reflection-seismograph reconnaissance which found anticlinal structure on which leases were acquired. The first well, The Texas Company's Z. N. Smith No. 1, center of NE. ¼, NW. ¼, Sec. 2, T. 5 N., R. 12 W., was drilled, on the basis of this information, with location on the most favorable part of the structure. This well was begun in September, 1938, and was drilled to the Viola where casing was set and, due to the activity in other areas, it remained at that stage until July, 1940, at which time drilling was resumed. Showings of oil and gas were encountered in the Hunton, Sylvan, and Viola in this well which had 1,170 feet of Viola and 565 feet of Bromide (dense) before it re-entered the Viola at 4,278 feet. An additional 118 feet of Viola was drilled and the well was abandoned at the total depth of 4,396 feet.

Location for Z. N. Smith No. 2, center of SE. ¼, NW. ¼, Sec. 2, T. 5 N., R. 12 W., was then made and the sequence and thickness of beds in this well were found

[1] Read before the Tulsa Geological Society, May 1, 1944. Manuscript received, November 29, 1944.

[2] Geologist, The Texas Company.

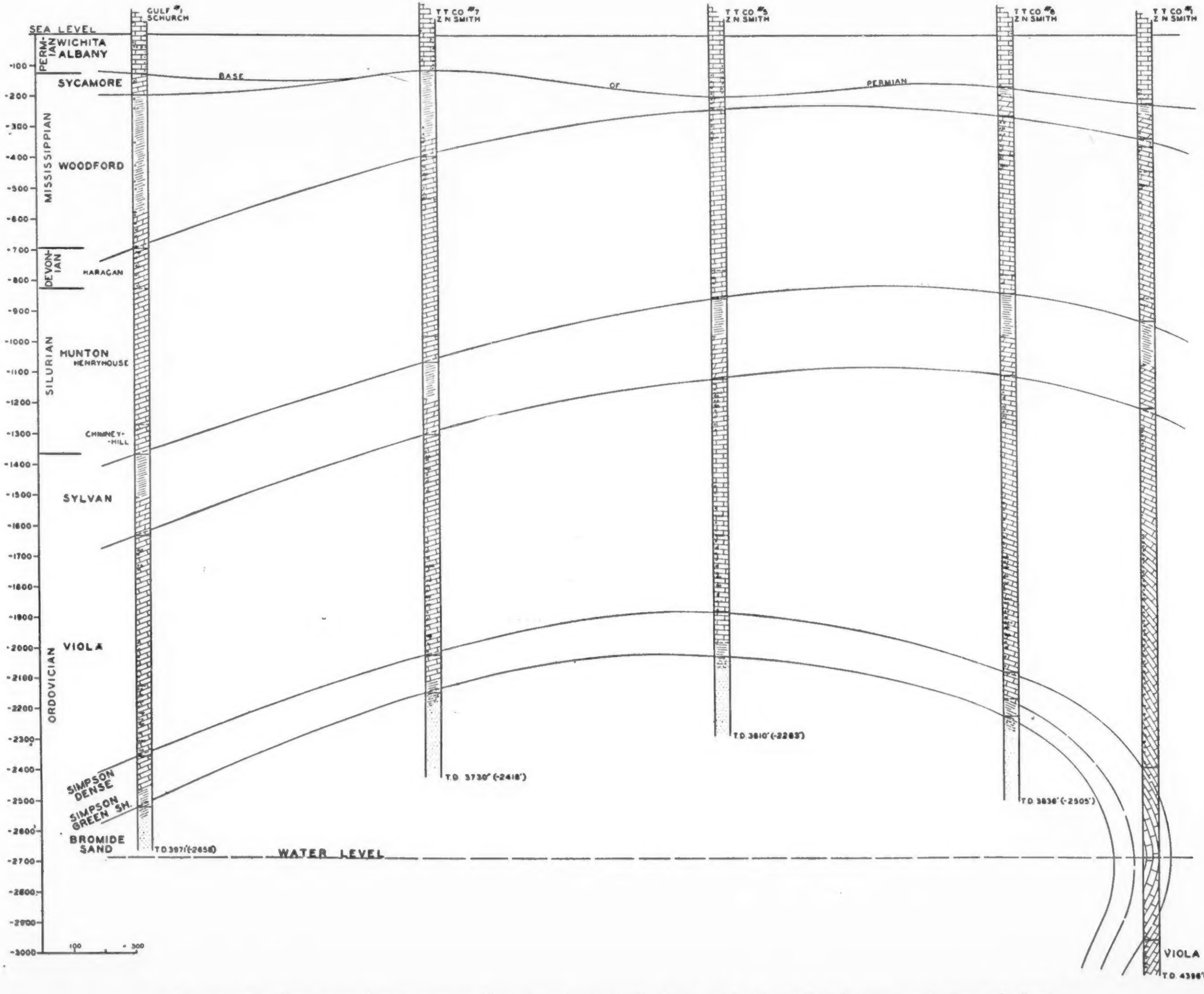

FIG. 1.—Southwest-northeast cross section, Apache pool. Vertical and horizontal scale are equal; shown in feet.

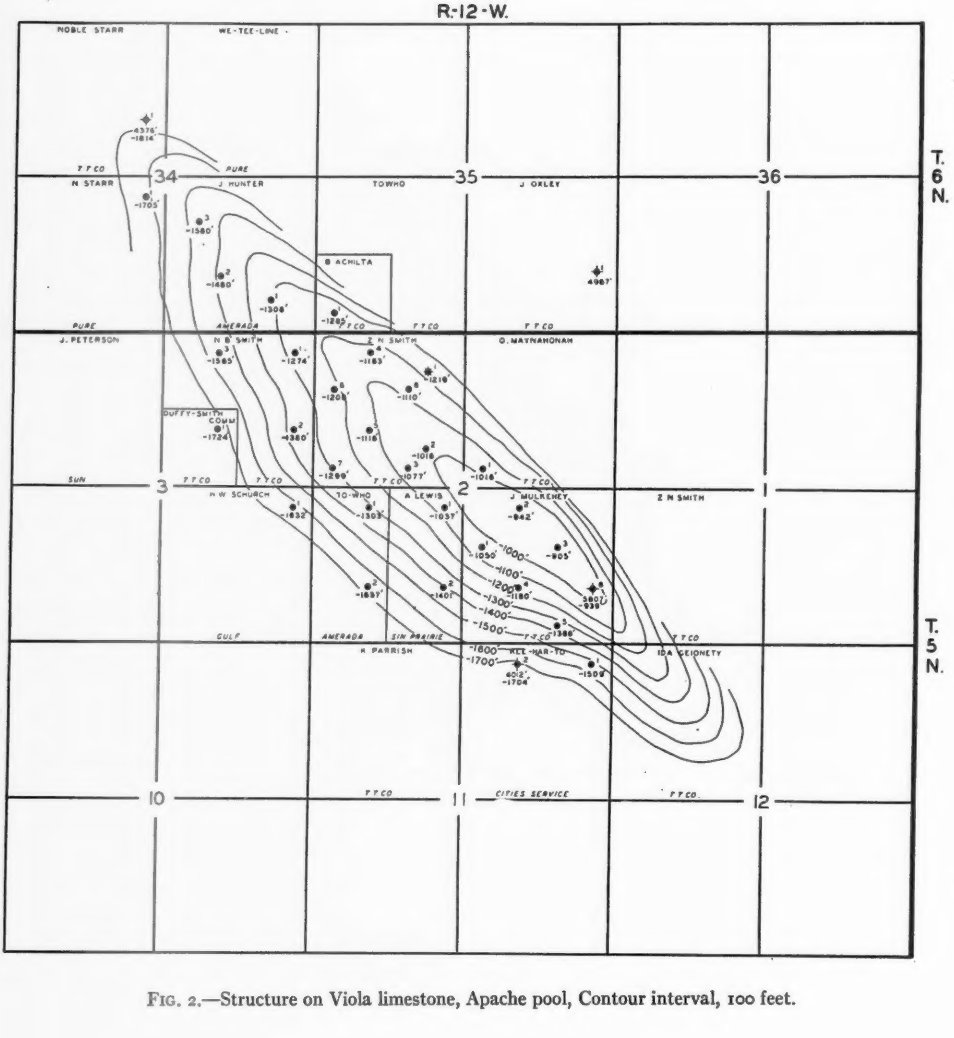

FIG. 2.—Structure on Viola limestone, Apache pool, Contour interval, 100 feet.

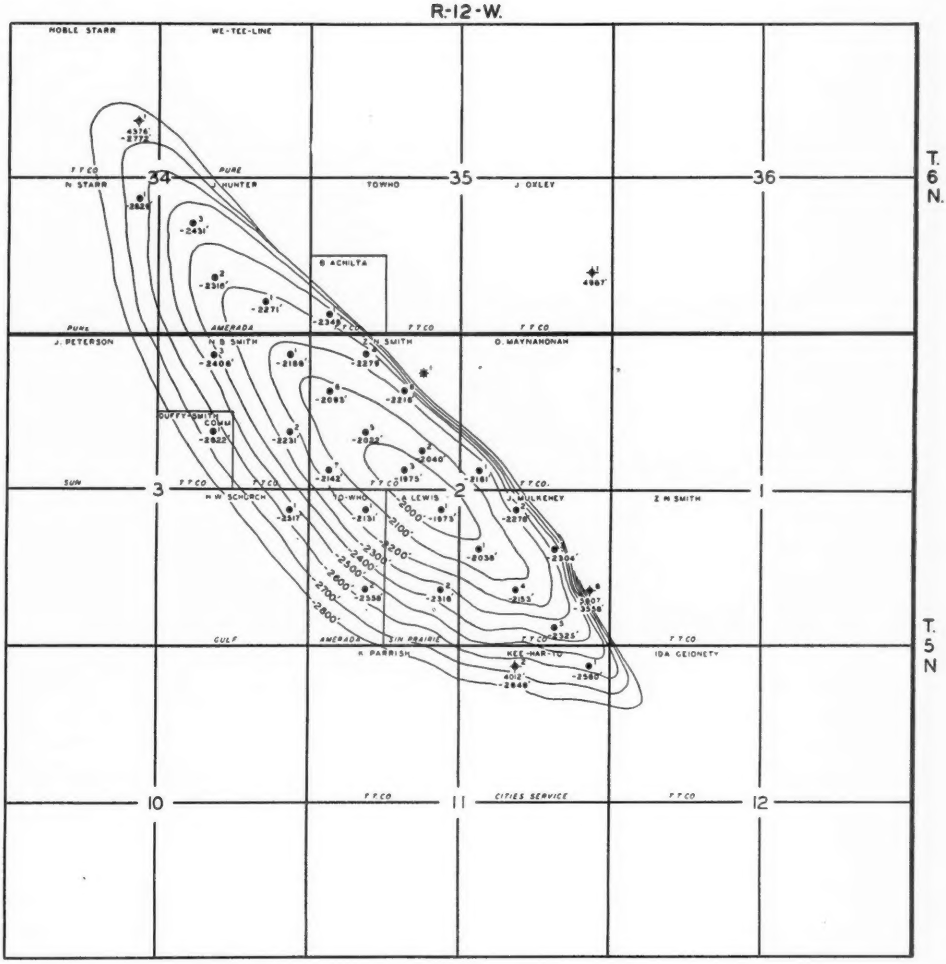

FIG. 3.—Structure on Bromide sand, Apache pool. Contour interval, 100 feet.

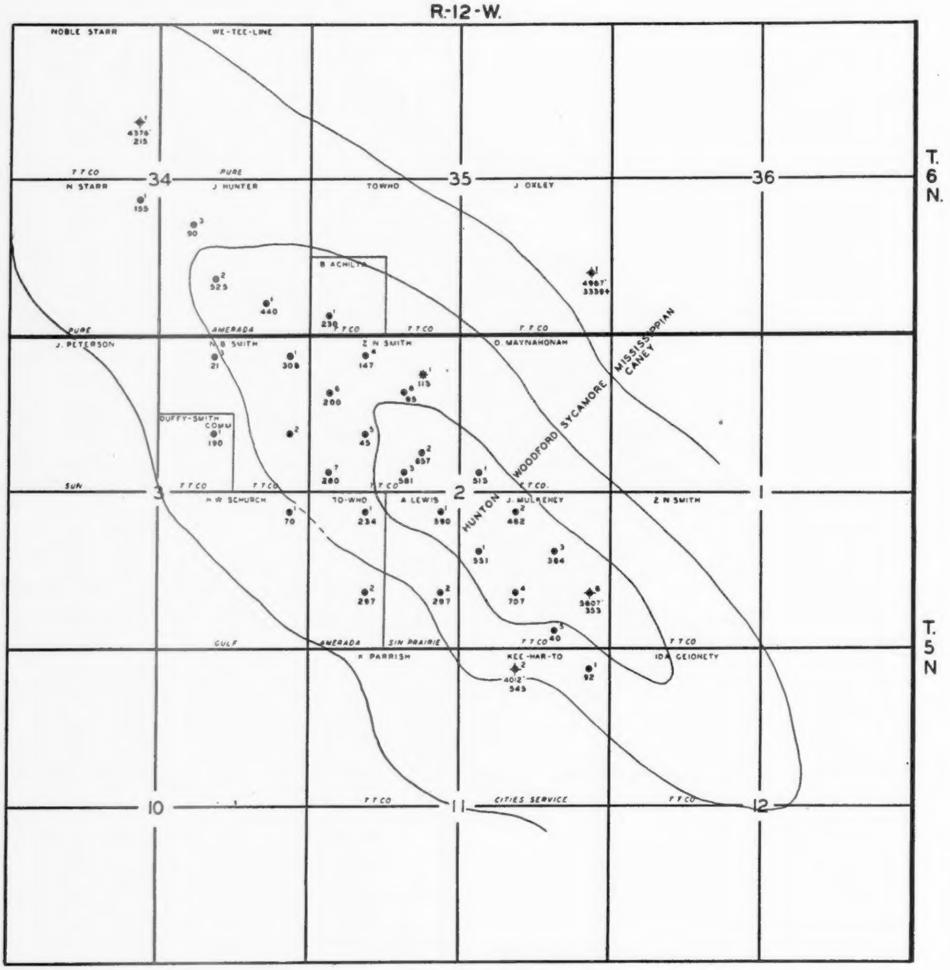

FIG. 4.—Pre-Permian paleogeologic map, Apache pool.

to be similar to those in well No. 1 until the base of the Permian was reached. This well then went from Permian to Hunton, 214 feet structurally higher than in well No. 1 which had had 113 feet of Woodford below the Permian. A normal sequence of Sylvan, Viola, Bromide (dense) and green shale and Bromide sand was found, with saturation in the sand. The well was originally completed, producing 1,500 barrels of 39.2° gravity oil. The total depth was 3,433 feet, which was 69 feet in the Bromide. The well was later deepened to 3,630 feet and, at completion, produced 10,000 barrels on potential test.

The stratigraphic section in the pool is typical in this part of the state, with 250–300 feet of Hennessey shale, 450 feet of Garber sandstone, and an average of 600 feet of limestone and conglomerate of Wichita-Albany age of the Permian. The Permian rests unconformably on the truncated surface of Mississippian Caney, Sycamore, and Woodford, which form a complete pattern around the Hunton which is the oldest formation exposed on the pre-Permian surface. The Texas Company's Oxley No. 1, NE. ¼, SE. ¼, SE. ¼ of Sec. 35, T. 6 N., R. 12 W., penetrated 3,339 feet of Mississippian Caney before it was abandoned. The Sycamore has an estimated thickness of 800–900 feet, although 215 feet is the thickest section penetrated. The Woodford ranges from a feather edge to 500 feet, the Hunton from 353 to 700 feet. The Sylvan is composed of 300 feet: an upper 150 feet of green shale and a lower 150 feet of dolomite. The Viola is 700 feet, the Bromide (dense) 100 feet, and green shale 50 feet in thickness. The Bromide sand has a 30-foot zone of non-productive sandy shale at the top and approximately 220 feet of soft, porous sand which is roughly divided into three zones by green shale stringers. The pay zone is one revervoir with a fairly uniform water level of minus 2,680 feet.

The structure is an anticlinal fold with the crest overturned toward the northeast, the axis trending northwest and southeast. No faulting of any importance is evidenced although there are probably small displacements of adjustments over the fold. There is 700 feet of structural closure with an average of 160 feet of productive sand over the entire area of 712 proved productive acres. The depth to the pay sand varies from about 3,300 feet to about 3,900 feet. The axis of the Viola structure is slightly east of the center of Sec. 2, T. 5 N., R. 12 W., but the Bromide structural axis has shifted toward the southwest. This change at the crest of the structure is at the rate of 700 feet of lateral shift southwestward with 1,000 feet of depth through the Viola-Bromide horizons. There are two wells, The Texas Company's Mulkehay No. 2 and No. 3, which are in the nearly vertical overturn. The No. 2 has penetrated 110 feet into the sand, and the No. 3 has penetrated 241 feet of sand.

This type of intense structure with well defined closure is particularly suitable to the application of pressure maintenance. There is little evidence to date of an effective water drive which will assist in the maintenance of the reservoir pressure.

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

AEROGEOLOGY IN MINERAL EXPLORATION, BY W. S. LEVINGS

Aerogeology in Mineral Exploration, by W. S. Levings. *Colorado School of Mines Quarterly*, Vol. 39, No. 4 (Golden, Colorado, October, 1944). 77 pp., 10 halftone inserts, bibliography. Price, $1.00, postpaid.

The primary purpose of the paper is to emphasize the possibilities of geological observations from the air, with special reference to aerial photographs taken from moderately great heights, as a powerful accessory to the modern equipment of the scientific explorer for mineral deposits.

Of secondary importance is the assembly in unit form of significant information concerning the results and techniques of aerial exploration, which, as a consequence of its being scattered in either relatively inaccessible publications or company files, has not been generally available to most interested persons.

Attention is directed to the existing critical situation of the national reserves of petroleum and the metals, due, in part, to the continued rate of decline of new mineral discoveries, and, in part, to the heavy withdrawals from storage occasioned by the extraordinary demands of the Allied war machine. The suggestion is advanced that the potentialities of aerogeology as an efficient prospecting instrument have not received due recognition, particularly from the mining industry.

After a brief survey of the various types of aerial photographs and of aerial equipment and flying routine, the unique advantages of the air view, as contrasted with that obtainable on the ground, are developed in detail. The conditions under which geological inferences from the air are justified and the various criteria that serve as a basis for such inferences are discussed from the viewpoint of experienced observers in this field. The absolute necessity of qualified interpreters for satisfactory results is stressed.

PETROLEUM DEVELOPMENT AND TECHNOLOGY, 1944, BY A.I.M.E. PETROLEUM DIVISION

REVIEW BY A. N. MURRAY[1]
Tulsa, Oklahoma

Petroleum Development and Technology, 1944, by A.I.M.E. Petroleum Division, *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 155. 581 pp., illustrated. Published by the Institute at the offices of the secretary, 29 West 39th Street, New York 18, N. Y. Price, $5.00.

This volume contains the papers and discussions presented before the Petroleum Division at the meetings held at Los Angeles, October, 1942, and October, 1943; Austin, October, 1942; Dallas, May, 1943; and New York, February, 1943, and February, 1944. Production statistical reports for the states producing petroleum are also included. The papers presented at the meeting treat mostly of engineering problems and practices, but the geologist may profitably read many of them, for often his problems are intimately related to those of the production engineer.

Chapter I, "Exploration," is composed of four papers the first one of which, "Deep Drilling Prospects in the Mid-Continent," is of interest to all geologists, and the second,

[1] Department of geology, University of Tulsa. Review received, December 20, 1944.

"Waters from the Frio Formation, Texas Gulf Coast," is geological in nature. The two remaining papers deal with natural potentials.

Chapter II, "Production Engineering Research," contains 14 papers. Of this number, two, "Engineering Features of the Schuler Field and Unit Operation" and "A Study of the Smackover Limestone Formation and the Reservoir Behavior of Its Oil and Condensate Pools," are worthy of the geologist's attention. The remainder of the papers, all of which are highly specialized, deal mostly with reservoir behavior and conditions, and physical phenomena encountered in production engineering.

Chapter III, "Petroleum Economics," consists of two papers each of which is given in summary. The titles, "Sources, Disposition, and Characteristics of the Capital Employed by Thirty Oil Companies during the Nine-Year Period 1934–1942" and "Possibility of Converting the Large-Diameter War Emergency Pipe Lines to Gas Service after the War," give the gist of the papers. Complete copies of these papers, which are respectively "Contribution No. 133" and "Contribution No. 135," are available at the Institute headquarters, New York.

Chapter IV, "Production," is, as in previous volumes, composed of summary statements of developments and production tables for each state arranged in alphabetical order according to states, with the following exceptions: (1) the Rocky Mountain states are grouped under Rocky Mountain region; (2) the paper treating of production in the Texas Panhandle is to be found on page 575 following Chapter V. The only paper covering a foreign area is "Oil Possibilities in Brazil."

Chapter V, "Refining," consists of one paper, "Review of Refining Engineering for 1943," which gives interesting information on some of the petroleum products that are used in large quantities in the war effort and the progress in the construction of plants that are to produce them.

OIL AND GAS FIELD DEVELOPMENT IN THE UNITED STATES, 1943, BY NATIONAL OIL SCOUTS AND LANDMEN'S ASSOCIATION

REVIEW BY A. N. MURRAY[1]
Tulsa, Oklahoma

Oil and Gas Field Development in the United States, 1943, by National Oil Scouts and Landmen's Association. *Year Book 1944, Review of 1943,* Vol. XIV. 664 pp. (7.75×10.5 inches), tables, maps, diagrams. Published by the National Oil Scouts and Landmen's Association, Austin, Texas. Price, $7.50.

This volume is the largest year book by 86 pages that the National Oil Scouts and Landmen's Association has published to date. It contains the usual wealth of tabulated data and information as well as numerous maps, graphs, and diagrams on oil and gas developments in the United States during 1943. The largest part of the volume, pages 11 to 765, treats of the developments and activities in 29 states. A small part, pages 766 to 807, is devoted to papers; the remainder, pages 808 to 858, constitutes the appendix.

The part of the volume devoted to the developments and activities in the various states contains quantities of information. An idea of the scope of the information given on active oil-producing states may be obtained by taking Kansas as an example. For this state the following are treated: "Oil Fields Discovered," "Gas Fields Discovered," "Natural Gasoline Plants," "Refineries," "Kansas Oil Pool Map," "Rocks in Kansas," "Twentieth Anniversary of the Fairport Field," "Block Assemblages," "Distribution of Blocks by Areas," "Wildcat Well Record," "Geophysical Prospection," "Stratigraphic Tests," "Pipe Line Runs," "Barrels of Crude Oil Produced 1917–1943," "Blocks by Method of

[1] Department of geology, University of Tulsa. Review received, December 20, 1944.

Exploration," "Steel Storage and Oil in Storage January 1, 1944," "Pipe Line Construction," "Oil Fields of Kansas," "Oil Fields Combined," "Total Operations 1943," "Carbon Black Plants." States that are of current interest and that have previously produced little or no oil are as thoroughly treated as the more important ones. In the 11 pages devoted to North Dakota the reader will obtain an excellent summary of the general geology in this state in addition to the records of past and present petroleum prospecting.

In the small section devoted to papers, only one of the four presented is definitely geological. This is the paper "Deeper Drilling Prospects in the Mid-Continent" by A. R. Denison. Two others, "Classification of Exploratory Drilling and Statistics for 1943" and "Oil Reserves in the United States 1943," are also of interest to geologists.

The appendix contains 59 tables, charts, and maps occupying 50 pages. The contained information is varied, opening with a table of production and stocks, continuing with such data as a table of depths to new producing zones, a table on world crude-oil production, and closing with a list of the major 100-octaine plants.

This most valuable volume is so widely known that it needs no introduction or recommendation; however, it should be mentioned that it is the largest, most complete and authentic compilation of data and information relating to exploration, production, and transportation that is available.

RECENT PUBLICATIONS

ALABAMA

*"Southwestern Alabama," *The First Field Trip of the Southeastern Geological Society, June 21, 22, 23, 1944.* 23 pp., 5 stratigraphic and columnar sections and 1 map. Mimeographed in paper covers, 8.5×11 inches. "Upper Cretaceous of West-Central Alabama," by Winnie McGlamery, pp. 1–4. "General Features of the Tertiary Formations in Alabama," by Lyman D. Toulmin, Jr., pp. 5–15. Herman Gunter, president of the society, Florida Geological Survey, Tallahassee, Florida.

CALIFORNIA

*"Radiolaria from Upper Cretaceous of Middle California," by Arthur S. Campbell and Bruce L. Clark. *Geol. Soc. America Spec. Paper 57* (New York, October, 1944). 61 pp., 8 pls., 2 figs.

*"Lost Hills, California—an Anticlinal Minimum," by Donald C. Barton. *Petrol. Tech.*, Vol. 7, No. 6 (New York, November, 1944), pp. 9–15; 2 figs. In "Case Histories and Quantitative Calculations in Gravimetric Prospecting," *ibid.* Introduction by Paul Weaver. *A.I.M.E. Tech. Pub. 1760.*

"Tertiary and Late Upper Cretaceous Stratigraphy of West Border of San Joaquin Valley, North of Panoche Creek, Fresno, Merced, and Stanislaus Counties, California." *U. S. Geol. Survey Prelim. Chart 6,* Oil and Gas Investig. Ser. (November, 1944). 15 graphic sections, an index map, and descriptive text. For sale by Director, U. S. Geol. Survey, Washington 25, D. C. Price, $0.50.

COLOMBIA

*"La Industria de Petroleo en Colombia" (The Petroleum Industry in Colombia), by E. Ospina-Racines. *Bol. Inst. Sudamericano Petrol.*, Vol. 1, No. 3 (Montevideo, Uruguay), pp. 249–73; 5 photographs, 7 tables, sketch maps showing company concessions and producing regions. In Spanish.

ECUADOR

*"Geologia de la Region Sud-Occidental de Ecuador" (Geology of Southwestern

Ecuador), by R. W. Landes. *Bol. Inst. Sudamericano Petrol.*, Vol. 1, No. 3 (Montevideo, Uruguay), pp. 191–200.

*"Notas sobre Estudios Micropaleontologicos de las Formaciones Cretaceas y Tertiarias en la Region Litoral del Ecuador" (Micropaleontology of Cretaceous and Tertiary Formations in Littoral Region of Ecuador), by Hans E. Thalmann. *Ibid.*, pp. 201–06.

*"Consideraciones Generales sobre la Exploracion del Petroleo" (General Aspects of Exploration for Petroleum), by Benjamin F. Zwick. *Ibid.*, pp. 207–16.

ENGLAND

*"The Stratigraphy of the Chalk of Sussex. Part III. Western Area. Arun Gap to the Hampshire Boundary, with Zonal Map," by Christopher T. A. Gaster. *Proc. Geologists' Assoc.*, Vol. 55, Pt. 3 (London, October 27, 1944), pp. 173–88; folded geological map.

GENERAL

"Report of the Committee on Marine Ecology as Related to Paleontology for 1943–1944," by Harry S. Ladd, chairman. *National Research Council Div. Geol. and Geog.* (2101 Constitution Avenue, Washington 25, D. C., November, 1944). 37 pp., mimeographed, paper binding, 8.25×10.75 inches. Price, $0.50.

*"Geophysical Methods Applied to Oil Prospecting," by J. McGarva Bruckshaw. *Jour. Inst. Petroleum*, Vol. 30, No. 250 (Manson House, 26, Portland Place, London, October, 1944), pp. 271–310; 25 figs.

*"Case Histories and Quantitative Calculations in Gravimetric Prospecting," by Donald C. Barton. *Petrol. Tech.*, Vol. 7, No. 6 (New York, November, 1944). 49 pp., 27 figs. Introduction by Paul Weaver. *A.I.M.E. Tech. Pub. 1760.*

*"The Interpretation of Earth-Resistivity Measurements," by Morris Muskat. *Ibid.* 7 pp., 4 figs.

GEORGIA

*"Southwestern Georgia," *Southeastern Geological Society Second Field Trip, November 15, 16, 1944.* 63 pp., 2 maps. Mimeographed in paper covers, 8.5×11 inches. "The Crystalline Basement," by A. S. Furcron, pp. 1–2. "The Coastal Plain of Georgia," by F. Stearns MacNeil, pp. 3–5. "Upper Cretaceous Series," by Stephen M. Herrick and Philip E. La Moreaux, pp. 6–20. "The Tertiary Formations," by F. Stearns MacNeil, pp. 21–40.

KANSAS

*"Tabular Description of Outcropping Rocks in Kansas," by Raymond C. Moore, John C. Frye, and John Mark Jewett. *Kansas Geol. Survey Bull. 52*, Pt. 4 (Lawrence, October, 1944), pp. 137–212; 9 figs.

*"Mined Areas of the Weir-Pittsburg Coal Bed," by G. E. Abernathy. *Ibid.*, *Bull. 52*, Pt. 5, pp. 213–28; 1 fig., 1 pl.

LOUISIANA

*"Gravity Minimum at Tepetate on Very Deep Salt Dome, Acadia Parish, Louisiana," by Donald C. Barton. *Petrol. Tech.*, Vol. 7, No. 6 (New York, November, 1944), pp. 15–22; 6 figs. In "Case Histories and Quantitative Calculations in Gravimetric Prospecting," *ibid.* Introduction by Paul Weaver. *A.I.M.E. Tech. Pub. 1760.*

MICHIGAN

"Thickness and Character of the Traverse Group and Dundee Formation in Southwestern Michigan." *U. S. Geol. Survey Prelim. Chart 4*, Oil and Gas Investig. Ser. (November, 1944) For sale by Director, U. S. Geol. Survey, Washington 25, D. C. and Michigan Geol. Survey, Lansing, Michigan. Price, $0.40.

OKLAHOMA

*"North Burbank May Be Largest Individual Secondary-Recovery Reserve," by Kenneth B. Barnes. *Oil and Gas Jour.*, Vol. 43, No. 24 (Tulsa, November 25, 1944), pp. 62–66; 4 figs.

PERU

*"Geologia de la Sierra de Cutucú Frontera Perú-Ecuador" (Geology of the Sierra Cutucú on the Border of Perú and Ecuador), by Victor Oppenheim. *Bol. Soc. Geol. Peru*, Vols. 14–15 (Lima, 1943), pp. 104–11; 2 figs.; 10 photographs. In Spanish.

SOUTH AMERICA

(TRINIDAD, VENEZUELA, AND ECUADOR)

*"Water for Oilfields Development," by G. W. Halse. *Jour. Inst. Petroleum*, Vol. 30, No. 250 (London, October, 1944), pp. 313–24; 12 figs.

TEXAS

*"Gravity Anomalies of Nash and Damon Mounds, Fort Bend and Brazoria Counties, Texas," by Donald C. Barton, *Petrol. Tech.*, Vol. 7, No. 6 (New York, November, 1944), pp. 2–9; 3 figs. In "Case Histories and Quantitative Calculations in Gravimetric Prospecting," *ibid.* Introduction by Paul Weaver. *A.I.M.E. Tech. Pub. 1760.*

URUGUAY

*"Memoria Explicativa del Mapa Geologico del Departamento de Colonia" (Explanatory Memoir of the Geological Map of Colonia), by Nicolas Serra. *Inst. Geol. Uruguay Bol. 30* (Montevideo, October, 1943). 50 pp., 9 geological profiles, 15 photographs, 1 geological map in colors. In Spanish.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Paleontology* (Tulsa, Oklahoma), Vol. 18, No. 6 (November, 1944)

"The Permian of Southernmost Mexico and Its Fusulinid Faunas," by M. L. Thompson and A. K. Miller

"Ostracoda from the Duplin Marl (Upper Miocene) of North Carolina," by Richard A. Edwards

"Auloporidae and Hederelloidea," by Maxim K. Elias

"*Hederella* and *Corynotrypa* from the Pennsylvanian," by G. E. Condra and M. K. Elias

"Fossiliferous Ordovician in Lowlands of Eastern Peru," by Norman D. Newell and Isaac Tafur

"A New Paleocene Catometope Crab from Texas, *Tehuacana tehuacana*," by H. B. Stenzel

"A New Cretaceous Crab, *Graptocarcinus muiri*, from Mexico," by H. B. Stenzel

"Paleoecology of Three Faunules in the Permian Kaibab Formation at Flagstaff, Arizona," by David Nicol

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Nevin R. Shade, Los Angeles, Calif.
Everett C. Edwards, Elmer L. DeMaris, R. O. Swayze
Warren James Souder, Evansville, Ind.
M. M. Knechtel, George T. Crouse, Kenneth L. Chasey
Walter Allen Stokesbary, Bakersfield, Calif.
DeWitt E. Taylor, Arne Junger, Lois T. Martin
George Alfred Thiel, Minneapolis, Minn.
Clinton R. Stauffer, A. I. Levorsen, John H. Nelimark
Charles Dalton Whitsitt, San Antonio, Tex.
W. Harlan Taylor, Philip H. Jennings, Frank C. Roper
Robert E. Woods, Altadena, Calif.
Everett C. Edwards, Elmer L. DeMaris, R. O. Swayze

FOR ASSOCIATE MEMBERSHIP

John Archibald Armstrong, Calgary, Alta., Canada
W. P. Hancock, J. D. Berwick, J. C. Sproule
Frank James Bell, Carmi, Ill.
George V. Cohee, A. J. Eardley, Kenneth K. Landes
William Morris Brodrick, Wichita, Kan.
F. E. Mettner, Wendell S. Johns, V. C. Scott
Dorothy MacGregor Dickson, Houston, Tex.
R. L. Beckelhymer, C. H. Sample, Fred M. Bullard
Arnold J. Fisher, Midland, Tex.
A. E. Barnes, Jr., J. P. Gries, W. C. Fritz
Donald E. Greenlee, Sacramento, Calif.
E. F. Davis, M. G. Edwards, Frank W. Bell
Frank Rogers Hunter, Fort Worth, Tex.
Joseph H. Markley, Jr., H. H. Bradfield, H. Giddings
Pedro Jesus Marquez G., Austin, Tex.
Hal P. Bybee, H. H. Power, F. L. Whitney
William Hall McConnell, Shawnee, Okla.
M. C. Roberts, V. C. Scott, L. H. Lukert
William Ernest Pelley, Casper, Wyo.
R. L. Belknap, A. J. Eardley, E. G. Cole
Donald Hoy Smith, Mattoon, Ill.
Jack Hirsch, V. C. Scott, Lester L. Whiting
Murrell D. Thomas, Salem, Ill.
Jack Hirsch, V. C. Scott, E. F. Stratton

Thaddeus Blair Vance, Mt. Pleasant, Mich.
V. C. Scott, Jack Hirsch, K. E. Adams
Byron K. Webb, South Gate, Calif.
C. M. Wagner, R. O. Swayze, E. C. Edwards
Robert Womack, Jr., Dallas, Tex.
Cecil G. Lalicker, William F. Absher, Brame Womack
Eleanor Jane Young, Rio Vista, Calif.
W. S. W. Kew, Allison J. Solari, J. M. Kirby

FOR TRANSFER TO ACTIVE MEMBERSHIP

Stewart Barclay, Caracas, Venezuela
H. W. O'Keefe, William Henry Courtier, A. J. Hintze
Leon Prestridge Bristley, Jr., Pittsburgh, Pa.
E. A. Eckhardt, Louis F. Melchior, L. L. Nettleton
Donald McClure Davis, Bakersfield, Calif.
Joseph LeConte, Robert J. Wells, Rollin Eckis
Gordon H. Fisher, Fort Worth, Tex.
H. M. Bayer, B. E. Thompson, J. B. Lovejoy
John Edward Gaffney, Midland, Tex.
Robert I. Dickey, F. H. McGuigan, W. D. Henderson
Kathleen K. Gilmore, Dallas, Tex.
Henry J. Morgan, George H. Norton, Willis G. Meyer
Raymond Charles Gutschick, Oklahoma City, Okla.
Walter L. Moreman, F. W. DeWolf, S. A. Thompson
Jack Hastings Heathman, Wichita, Kan.
Virgil B. Cole, Howard S. Bryant, Edward A. Koester
Harold J. Kleen, Oklahoma City, Okla.
Joseph E. Morero, Richard B. Rutledge, L. M. Wilshire
Thomas Edwards Matson, Tulsa, Okla.
Darsie A. Green, Louis Roark, J. V. Howell
Lloyd Clarence Mills, Midland, Tex.
Ronald K. DeFord, E. Russell Lloyd, Lynn K. Lee
Paul W. Netterstrom, Barrington, Ill.
L. R. Fortier, W. C. Bean, R. E. Shutt
Van Alvin Petty, Jr., San Antonio, Tex.
Hal P. Bybee, William H. Spice, Jr., P. J. Rudolph
Harold Greeley Picklesimer, San Antonio, Tex.
Worth W. McDonald, James K. Rogers, Hubert E. Menger
Donald James K. Polk, Baton Rouge, La.
Robert D. Sprague, Raymond D. Sloan, E. O. Markham
Gerald Clifford Roberts, Midland, Tex.
W. D. Henderson, W. D. Anderson, Robert I. Dickey
Charles Anderson Shaw, Midland, Tex.
Robert I. Dickey, Addison Young, S. C. Giesey

30TH ANNUAL MEETING, TULSA, MARCH 20–22, 1945

The 30th annual meeting of the Association will be held at the Mayo Hotel, Tulsa, Oklahoma, on Tuesday, Wednesday, and Thursday, March 20, 21, and 22, 1945, at the invitation of the Tulsa Geological Society. The Society of Exploration Geophysicists will meet on Tuesday and the Society of Economic Paleontologists and Mineralogists will meet on Thursday. This annual meeting in time of war will be restricted to business sessions and the most important technical and research conferences. No banquet, dance, or field trips are to be arranged.

BECAUSE OF LIMITED HOTEL SPACE, THERE WILL BE NO POSSIBILITY OF ACCOMMODATING WIVES. MEMBERS ARE REMINDED NOT TO COME TO THE MEETING UNLESS THEY HAVE A HOTEL CONFIRMATION OF A ROOM RESERVATION IN ADVANCE, OR UNLESS THEY HAVE A SPECIFIC ARRANGEMENT TO STAY IN A PRIVATE HOME. THE COMMITTEE CAN NOT OVEREMPHASIZE, UNDER WAR-TIME CONDITIONS, THE POSITIVE NEED FOR HAVING A DEFINITE AND CERTAIN ARRANGEMENT FOR ROOM ACCOMMODATIONS DURING THIS MEETING.

The executive committee desires to emphasize the necessity for limiting the attendance.

It will be impossible for all members to attend this war-time meeting. Transportation and hotel facilities are inadequate to accommodate everyone. Your generous thoughtfulness is urgently recommended to help relieve the situation. By observing the following requests you will help your fellow members and all others concerned. If you have already made such arrangements, please accept the thanks of the committee.

1. Hotel reservations will close on February 28.
2. Arrange with a friend to share a room with you. (If you do not, you may be requested to accept a roommate.) In requesting reservations, give your roommate's name and address, as well as your own.
3. Request reservations through the Mayo Hotel. (Do no request officers or local chairmen to make reservations for you.) If the Mayo can not accommodate you, it will try to place you in another hotel. If no hotel space is available, your request will be referred to the housing committee.
4. Do not bring wives or persons not directly interested in this meeting.
5. Do not come unless you have a confirmation of room reservation.
6. Cancel your Pullman and hotel reservations immediately if you are not coming.

Although the limited oral program will not provide time for the delivery of papers other than those of a very general nature it is highly desirable that all who can prepare papers make an effort to submit titles, abstracts, and complete manuscripts which may be placed on the programs BY TITLE, and later published in the *Bulletin*. Papers are needed for the monthly *Bulletin*, and it is desirable to include titles on the program of this meeting. Send titles and abstracts, before February 15, to A.A.P.G. Headquarters, Box 979, Tulsa 1, Oklahoma.

Following are the names of the officers and chairmen in charge of the arrangements.

Technical Program, A.A.P.G. Executive Committee
    Ira H. Cram, chairman, Pure Oil Company, Chicago
General Committee for Tulsa Arrangements
    W. B. Wilson, chairman, Gulf Oil Corporation
    A. Rodger Denison (A.A.P.G.), Amerada Petroleum Corporation
    Charles Ryniker (S.E.P.M.), Gulf Oil Corporation
    T. A. Manhart (S.E.G.), Seismograph Service Corporation
    J. V. Howell (Tulsa Geological Society), Philtower Building
Hotels and Housing, G. H. Westby, Seismograph Service Corporation
Technical Equipment, R. J. Cullen, Sun Oil Company
Registration, E. O. Markham, Carter Oil Company
Educational Exhibits, A. N. Murray, University of Tulsa
Publicity, H. J. Conhaim, Beacon Life Building
Reception, C. G. Carlson, Thompson Building

REPORT OF COMMITTEE ON CODE OF ETHICS[1]

C. W. TOMLINSON[2]
Ardmore, Oklahoma

We recommend that the following sentence be added to Section 4 of Article III of the constitution.

With the notice of election shall be included a copy of the constitution and by-laws of the Association.

We recommend that the present detailed Code of Ethics of the association be abolished. In its place, we recommend that the following sections be inserted in the constitution as part of Article III.

Professional Ethics

SECTION 7. Each member and associate shall be guided in all relations with employers, clients, fellow geologists, business associates, and the public, by the highest standards of business ethics, personal honor, and professional conduct.

SECTION 8. Any member or associate who, after due investigation, is found guilty of violating any of the standards of conduct prescribed in Section 7 of this Article, may be admonished, suspended, allowed to resign, or dropped from membership in accordance with the procedure provided in the by-laws.

We recommend that the following five sections be inserted in Article II of the by-laws in place of the present Section 5 thereof.

SECTION 5. Charges of misconduct in violation of Section 7 of Article III of the constitution shall first be submitted in writing to the president of the Association, in confidence, with a full statement of the evidence on which the charges are based. If in his judgment they merit further consideration, he shall appoint a committee to consist of three past-presidents of the Association, which shall examine into the charges. If in the judgment of said committee, the facts warrant, it shall prepare and file with the executive committee formal charges against the accused member or associate. As soon as may be after the receipt of such charges the executive committee shall fix a date and place for hearing thereupon, and shall give to the accused person notice thereof in writing, mailed to him by registered mail at his last known post office address not less than thirty (30) days before said date, accompanied by a copy of the charges, and a copy of this article.

SECTION 6. On the day fixed for the hearing, the accused person may appear before the executive committee, either in person or by an accredited representative; hear any witnesses who may be called in support of the charges; and, at his option, cross-examine the same, and hear read any documentary evidence, including a statement from himself in writing. At his option, he may by letter waive personal hearing, and request the executive committee to adjudge the matter on the basis of a written statement of his defense, mailed to the committee before the date set for the hearing. After the conclusion of the hearing, or study of written defense submitted in lieu of a personal hearing, the executive committee shall consider and vote to approve or disapprove the charges. If the executive committee shall, by unanimous vote, declare the charges sustained, it may suspend the accused person from membership for a stated period, admonish him, allow him to resign, or expel him. Failure of the accused person to appear either in person or by an accredited representative shall not prevent the executive committee from proceeding with the trial.

SECTION 7. If the accused person shall not appear at the hearing nor waive his right thereto, and shall within three months after the date set for the hearing file with the executive committee an affidavit stating that he had not received notice of the charges against him in time to enable him to present his defense, the executive committee shall fix a date and place for a hearing not less than

[1] Manuscript received, December 1, 1944. This report has been submitted to the executive committee in accordance with the business committee recommendation adopted by the Association in annual meeting at Dallas, March 23, 1944: "The business committee also recommends that the executive committee appoint a special committee to formulate a revised code of ethics to be submitted to the Association for adoption at the next annual meeting, and that a copy of the new proposed code be placed before the membership-at-large through the medium of the *Bulletin* at least 60 days prior to the next annual meeting."

[2] Chairman of the committee. The other members of the committee are: Raymond F. Baker, New York; Orval L. Brace, Houston; Harold W. Hoots, Los Angeles; and T. S. Harrison, Denver.

thirty days nor more than three months from the receipt of such affidavit, and shall immediately notify the accused person by registered mail of such date and place. Upon the rehearing, the proceedings shall be governed by the provisions of Section 6 of this Article.

SECTION 8. Resignation of the accused person from membership in the Association, at any stage of the foregoing prescribed proceedings, shall automatically terminate the proceedings.

SECTION 9. The decision of the executive committee in all matters pertaining to the interpretation and execution of the provisions of Sections 5, 6, and 7 of this Article shall be final.

ANNOUNCEMENT AND RULES OF THE PRESIDENT'S AWARD[1]

IRA H. CRAM[2]
Chicago, Illinois

From time to time there have been suggestions that the Association should take some recognition of the work done by the younger geologists. These suggestions have frequently been directed toward the stimulation of these younger men to write articles for the *Bulletin.* One such suggestion was discussed at some length in March, 1944, by the medal award committee. As a result of this discussion, the committee formulated rules and regulations for an award and submitted them to the executive committee. On October 8, 1944, the executive committee established "The President's Award" and promulgated the accompanying rules.

Briefly stated, the award is $100 in cash for the best paper published in the *Bulletin* during each calendar year by an author who has not reached his 40th birthday on January 1 of the year in which the article appears.

The first of these awards will be made for an eligible article published during the year of 1944. The first presentation of the award will be at the annual meeting, March 21–22, 1945, in Tulsa.

Rules for the President's Award[3]

NAME

The name of the award shall be "The President's Award of The American Association of Petroleum Geologists."

PURPOSE

The purpose of the award is to honor and reward the younger authors of original articles published in the *Bulletin* of the Association during each calendar year.

AWARD

The award shall consist of $100 in cash plus a suitably worded certificate of award.

ELIGIBILITY

Author(s).—The author(s) of each article published in the *Bulletin* is (are) eligible, provided, he (they) has (have) not reached his (their) 40th birthday on January 1 of the year in which the article is published.[4]

Articles. The article may be on any subject having to do with the broader phases of petroleum geology but must represent a report of work of an original character primarily by the author(s).

[1] Manuscript received, December 18, 1944.

[2] Chairman, executive committee.

[3] Adopted by the executive committee, November 8, 1944.

[4] This age limit is arrived at due to the present war emergency and the consequent large number of junior members now in the Armed Forces. It is suggested that this age limit be retained for the years 1944, 1945, and 1946, and that thereafter it be reconsidered with the thought that it should be lowered to 35 years.

FUNDS

The money for this award shall come from the General Fund of the Association, and shall be made available by affirmative action of the executive committee after request by the medal award committee.

SELECTION OF RECIPIENT

It shall be the duty of the medal award committee to select the article which, in its opinion, makes the most significant contribution to petroleum geology. All articles by eligible authors published in the *Bulletin* during each calendar year shall be considered in making this award. For this purpose the committee may request assistance of the editor, the associate editors, or others. Their selection shall be regarded as final after approval by the executive committee.

In case an article is selected having joint eligible authors the monetary award shall be divided among the authors and duplicate certificates of award shall be presented. In all other cases involving joint authors the medal award committee may divide the honors in any manner which it may decide.

On all questions which may arise where these rules do not specifically cover the situation the committee may decide the question by a majority vote.

PRESENTATION OF AWARD

The chairman of the medal award committee shall on or before February 1 of each calendar year advise the executive committee of the selection by the committee from articles published during the preceding year. On approval of the selection and appropriation of the necessary funds by the executive committee, the chairman of the medal award committee shall arrange for the presentation of the award at the annual meeting following February 1.

REVISION OF RULES

These rules may be revised or amended at any time by (1) action of the executive committee, (2) recommendation of the medal award committee and approval by the executive committee. The right to revise and amend shall include suspension or abolishment of the award.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 29, NO. 1 (JANUARY, 1945), PP. 120-121, 1 FIG.

MEMORIAL

CARL ST. JOHN BREMNER

(1895–1944)

It was hard to believe that Carl Bremner was really lost, when the news came to San Francisco that no word had been heard from the aeroplane he boarded at Lima, Peru, on September 18, 1944, *en route* northward along the coast. After several days of waiting, confirmation came of the crash of the plane in which all the passengers and crew were killed.

It was hard to believe, because Bremner had been in so many dangerous places and also had been a pilot in the first world war. In every experience, he had used his judgment and ingenuity to bring himself out of tight places without injury. He liked to fly and traveled in that manner whenever possible. He got a thrill flying past Chimborazo Peak and over the volcano Paracutin during an eruption. It was on his last trip home that he saw Paracutin from the air and was full of the excitement of it all when I met him at the airport in Burbank. Little did I think that he would not return when his son, Bob, and I said good-bye to him at the same airport 2 weeks later.

Carl Bremner was born in San Francisco on September 11, 1895. His mother was also a native Californian, having been born in Sacramento. His father, a Scotchman, came to California in the early days. He was the youngest of three children. His two sisters, Miss Georgina Bremner and Mrs. E. R. Kauffman, both reside in San Francisco. As a youngster, he attended St. Matthew's School in San Mateo and then, when his family moved to Santa Cruz, he went to the high school there, from which he graduated. The following 2 years he was at the University of California when World War I interrupted his college course.

During the war, he served as a Second Lieutenant in the Army Air Corps. After the

war, he returned to the University where he graduated with honors in 1921 and continued graduate work in geology for an additional year. While he was at the University, his sister Georgina studied geology with him.

His first job was with Carl H. Beal, at that time a consulting geologist in San Francisco. He was married in 1923 to Miss Marie Ryan who lived in Berkeley. In this year he joined the geologic staff of the Standard Oil Company of California. During the 21 years he was with this company, most of his work was in foreign countries—Venezuela first, then Dutch East Indies, New Guinea, Australia, New Zealand, and last, the West Coast of South America where he was chief geologist for the California Ecuador Petroleum Company.

During the relatively short periods he was in this country, he worked with me in California, usually in Ventura and Santa Barbara counties. In the course of this work he made detailed studies of the Channel Islands. Reports on Santa Cruz, San Miguel, and Santa Barbara islands of this group were published by the Santa Barbara Museum of Natural History.

It was during one of his assignments in California that he purchased some land in the Hope Ranch near Santa Barbara and built his beautiful home on the top of a hill. From here he could see the complexities of the geology of Santa Barbara with the strata folded into the background of the Santa Ynez Mountains, a truly inspiring sight. Mrs. Bremner now lives there with her two sons, Robert and Richard, and her mother, Mrs. Ryan. Robert, who attended Stanford University for a year, is now in the United States Navy.

Bremner was a geologist with much and varied experience. His mind was quick and he could grasp readily the salient facts of a geologic problem. For that reason, he pioneered the geology of many lands. He was resourceful, as one must be in penetrating for the first time the wildest parts of New Guinea. His good nature and wit made him a multitude of friends in this country and abroad. His good sense of humor was expressed in the many stories of incidents in his trips, such as outsmarting the Motilone Indians in Venezuela and keeping just ahead of New Guinea head-hunters who were after his life for accidentally killing a pig.

He loved the life of travel and of foreign lands and though his death was most untimely, it came while he was doing what he enjoyed.

He was buried in the English Cemetery, Bellavista, at Lima, Peru, South America, a part of the world he liked so well.

W. S. W. Kew

San Francisco, California
November 7, 1944

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 29, NO. 1 (JANUARY, 1945), PP. 122-124

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

New officers of the Society of Economic Paleontologists and Mineralogists, elected by mailed ballot in November, 1944, to take office after the annual meeting in March, 1945, are: president JOHN R. SANDIDGE, Magnolia Petroleum Company, San Antonio, Texas; vice-president, J. BROOKES KNIGHT, Princeton University, Princeton, New Jersey; secretary treasurer, H. B. STENZEL (re-elected), Bureau of Economic Geology, Austin, Texas.

JAMES H. MORRIS recently resigned from the United States Geological Survey to go with the Sohio Petroleum Company. He is stationed at Laurel, Mississippi.

CHESTER CASSEL, recently with the Military Unit of the United States Geological Survey at Washington, D. C., is now with the Union Oil Company, 617 West 7th Street, Los Angeles, California.

The air-mail address of HERMAN A. FONVILLE, of Wichita Falls, Texas, is Colombian Gulf Oil Company, Apartado Aereo 4014, Bogota, Colombia, South America.

Lieutenant JACK W. DAVIES has returned from 2 years of work on the Canol Project, Canada. His present address is Co. N, O.S.B., S.S.R., 46th F.O.C., Fort Belvoir, Virginia.

The Oklahoma City Geological Society heard CHARLES N. GOULD on "Geology of the Anadarko Basin," at its technical meeting at Oklahoma City University, December 20, following an informal dinner honoring Dr. Gould at the Skirvin Hotel. On January 4, the Society heard FRANK A. MELTON, of the University of Oklahoma on "Limitations of Aerial Photographs."

The program of the South Texas Geological Society, at the St. Anthony Hotel, San Antonio, December 21, included "Geology of the Isthmus of Tehuantepec," by PAUL WEAVER of Houston, and "Geology of the Tampico Oil Fields and Correlations with South Texas," by E. L. PORCH, JR., of San Antonio.

Major WILBUR B. SHERMAN, formerly with the Superior Oil Company at Los Angeles, California, has been promoted from the rank of captain according to an announcement by Colonel Oscar A. Heinlein, Regional Control Officer for the Third Weather Region. Major Sherman has been serving as Operations Officer for the Third Weather organization at headquarters in the Milam Building, San Antonio, since last May. His duties entail the supervision and coordination of the technical aspects pertaining to the operation of Army Air Forces weather stations in seven southwestern states comprising the Third Weather Region.

H. A. IRELAND, of the United States Geological Survey, at Norman, Oklahoma, spoke before the Tulsa Geological Society, December 18, on "Regional Correlation and Subsurface Studies of the Arbuckle Group of Rocks in Oklahoma."

The following are the new officers of the Dallas Petroleum Geologists: president, HENRY C. CORTES, Magnolia Petroleum Company; vice-president, CECIL H. GREEN, Geophysical Service, Inc.; secretary-treasurer, WILLIS G. MEYER, of DeGolyer and MacNaughton; executive committee, HENRY J. MORGAN, Atlantic Refining Company.

IRA H. CRAM, of the Pure Oil Company, Chicago, Illinois, and president of the Association, has recently visited the following affiliated societies and has discussed affairs of the A.A.P.G. with these groups: the Mississippi Geological Society, at Jackson, December 1; the New Orleans Geological Society, at New Orleans, December 4; and the Houston Geological Society at Houston, December 7.

S. F. SHAW is completing some gas-lift tests on wells in the Saxet field, and was in eastern Wyoming, checking oil properties during December and January.

J. M. WANENMACHER has resigned from Shell Oil Company, after 12 years service as

subsurface specialist and division exploitation engineer to join C. H. KEPLINGER in establishing a consulting practice in petroleum engineering. The partnership which is known as Keplinger and Wanenmacher has offices in the Kennedy Building, Tulsa, Oklahoma.

W. E. WALLACE, JR., of the Sohio Petroleum Corporation, Shreveport, Louisiana, appeared before the South Louisiana Geological Society, at Lake Charles, December 18, for a discussion of the more theoretical aspects of his paper, "Structure of South Louisiana Deep-Seated Domes," which was published in the September *Bulletin.*

Officers of the Kansas Geological Society, Wichita, Kansas, elected for the year 1945 are: president, VIRGIL B. COLE, Gulf Oil Corporation; vice-president, LAURENCE C. HAY, consulting geologist, 402 Union National Bank Building; secretary-treasurer, EDWARD A. HUFFMAN, c/o J. M. Huber Corporation, 407 First National Bank Building.

G. H. SCOTT has left the Apex (Trinidad Oilfields, Limited) to join the North Venezuelan Petroleum Company, Ltd., at Caracas, Venezuela.

STUART K. CLARK, of the Continental Oil Company, Ponca City, Oklahoma, formerly assistant chief geologist, has been appointed chairman of the company's committee on exploration.

PARK J. JONES, production consultant of Houston, Texas, is the author of a series of articles of the "Mechanics of Production," now appearing in the *Oil and Gas Journal.*

H. R. HOSTETTER, formerly geologist with the Shell Oil Company, Inc., is a core-drilling operator at Monroeville, Alabama.

MILAN D. MARAVICH, recently with the Petroleum Administration for War at Tulsa, Oklahoma, is with the Stanolind Oil and Gas Company, with headquarters at Wichita, Kansas.

JOSEPH E. POGUE and FREDERICK G. COQUERON are the authors of "Capital Employed in the Petroleum Industry," a 5-page article published in *Mining and Metallurgy* November, 1944.

W. A. BRUCE, of the Carter Oil Company, gave a paper on "Reservoir Behavior in Smackover Lime Pools," before the Shreveport Geological Society, October 23.

SAM GRINSFELDER, Houston, Texas, is vice-president of the Union Oil Company of California, in charge of work in Texas, Louisiana, Florida, Mississippi, and Alabama.

E. K. SOPER, associate professor of geology at the University of California at Los Angeles, and consulting petroleum geologist for the State of California, has returned to Los Angeles from Washington, D.C., where he has recently been in the Petroleum Division of the Department of State.

C. W. TOMLINSON, Ardmore, Oklahoma, consulting geologist, gave a paper "Correlation of the Pennsylvanian of North America," before the Shawnee Geological Society at the meeting on November 21, 1944.

At a regular meeting of the Rocky Mountain Association of Petroleum Geologists held at Denver, Colorado, November 6, the following officers were elected: president, J. J. ZORICHAK, Office of the Petroleum Administration for War; first vice-president, JOHN VANDERWILT, geologist, Climax Molybdenum Company; second vice-president, MAX L. KRUEGER, geologist, Union Oil Company of California; secretary-treasurer, ROBERT McMILLAN, geologist, Frontier Refining Company.

RUSSELL H. DICKEN, of the Republic Oil Company, is stationed at Miami, Florida.

DART WANTLAND is with the Seismograph Service Corporation, 709 Kennedy Building, Tulsa, Oklahoma.

NICHOLAS A. ROSE, of the United States Geological Survey, spoke before the Houston Geological Society, December 7, on "Relation of Phenomenal Rise of Water Levels to a Defective Well in Harris County, near Houston, Texas."

EDMONDSON D. LUMAN, of Tulsa, Oklahoma, died on December 9, at the age of 47

years. He was with the Atlantic Refining Company for many years before he became an independent operator.

C. B. ROACH, of the Shell Oil Company, Inc., and president of the South Louisiana Geological Society of Lake Charles, has been transferred by his company to the Cia. de Petroleo Shell de Colombia, Apartado 114, Bogota, Colombia. He is chief exploitation engineer.

Major ROE AUSTIN GRAY, formerly in Los Angeles as petroleum engineer with the General Petroleum Corporation, is now chief of Training Branch III of the basic technical training group at Camp Claiborne, Louisiana, where all of the army's pipeline companies are trained.

The Shreveport Geological Society has commenced work on a book which will summarize the salient geological and engineering features and statistics of more than fifty of the important oil and gas fields of South Arkansas, North and Central Louisiana, and Mississippi. It will also have at least one paper and several cross sections on a regional scale. It is hoped that such a publication, which will be issued in the Spring, will be useful to geologists and others engaged in the oil industry who are interested in the area. It is to be edited and published by the Field Trip Committee of the Shreveport Geological Society, of which T. H. PHILPOTT is chairman.

CLYDE F. DAVIS, with the Halliburton Oil Well Cementing Company, Duncan, Oklahoma, gave a paper on the "Interpretation of Electric Well Logs," before the Shawnee Geological Society meeting on December 14, 1944.

New officers of the Shawnee Geological Society, Shawnee, Oklahoma, elected on December 14, are: president, ALLEN EHLERS, Carter Oil Company, Box 1151, Seminole; vice-president, JOHN P. LUKENS, Oklahoma Seismograph, 1103 North Philadelphia, Shawnee; secretary-treasurer, MARCELLE MOUSLEY (re-elected), Atlantic Refining Company, Box 169, Shawnee.

DISTINGUISHED LECTURE TOUR

CHARLES E. WEAVER, professor of geology and paleontology at the University of Washington, Seattle, Washington, discussed "The Geology of Oregon and Washington and Its Relation to the Possible Occurrence of Oil and Gas" before several of the affiliated societies in the course of a transcontinental tour in January. He gave the conclusions he has reached after years spent in studying the geology of the Pacific Northwest, and expressed himself clearly on its possibilities for the production of oil and gas in commercial amounts.

In the course of his trip Dr. Weaver addressed the following societies.

January	2	Illinois Geological Society at Mount Vernon
	3	Indiana-Kentucky Geological Society at Evansville
	8	New Orleans Geological Society at New Orleans
	9	South Louisiana Geological Society at Lake Charles
	10	Houston Geological Society at Houston
	11	Fort Worth Geological Society at Fort Worth
	12	Oklahoma City Geological Society at Oklahoma City
	15	Tulsa Geological Society at Tulsa
	16	Kansas Geological Society at Wichita
	18	Rocky Mountain Association of Petroleum Geologists at Denver
	22	Pacific Section American Association of Petroleum Geologists at Los Angeles
	23	San Joaquin Geological Society at Bakersfield

JOHN L. FERGUSON, *chairman*

TEXAS

GEOLOGICAL AND GEOPHYSICAL SOCIETIES

COLORADO

ROCKY MOUNTAIN ASSOCIATION OF PETROLEUM GEOLOGISTS
DENVER, COLORADO

President - - - - - - - - - J. J. Zorichak
Petroleum Administration for War
First National Bank Building
1st Vice-President - - - - - John Vanderwilt
Climax Molybdenum Company
2nd Vice-President - - - - Max L. Krueger
Union Oil Company of California
Secretary-Treasurer - - - - Robert McMillan
Frontier Refining Company
First National Bank Building

Luncheons every Friday noon, Cosmopolitan Hotel. Evening dinner (6:15) and program (7:30) first Monday each month or by announcement, Cosmopolitan Hotel.

ILLINOIS

ILLINOIS GEOLOGICAL SOCIETY

President - - - - - - - - - Fred H. Moore
Magnolia Petroleum Co., Box 535, Mt. Vernon

Vice-President - - - - - - - - Lee C. Lamar
Carter Oil Company, Box 568, Mattoon

Secretary-Treasurer - - - - Everett F. Stratton
Schlumberger Well Surveying Corporation, Box 491, Mattoon

Meetings will be announced.

INDIANA-KENTUCKY

INDIANA-KENTUCKY GEOLOGICAL SOCIETY
EVANSVILLE, INDIANA

President - - - - - - - - - Robert F. Eberle
The Superior Oil Company

Vice-President - - - - - - - Stanley G. Elder
Sun Oil Company

Secretary-Treasurer - - - - Hillard W. Bodkin
The Superior Oil Company

Meetings will be announced.

KANSAS

KANSAS GEOLOGICAL SOCIETY
WICHITA, KANSAS

President - - - - - - - - - Virgil B. Cole
Gulf Oil Corporation
Vice-President - - - - - - - Laurence C. Hay
Consulting Geologist, 402 Union National Bank Building
Secretary-Treasurer - - - Edward A. Huffman
J. M. Huber Corporation, 407 First National Bank Building

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. The Society sponsors the Kansas Well Log Bureau, 412 Union National Bank Building, and the Kansas Well Sample Bureau, 137 North Topeka.

LOUISIANA

NEW ORLEANS GEOLOGICAL SOCIETY
NEW ORLEANS, LOUISIANA

President - - - - - - - - - Dean F. Metts
Humble Oil and Refining Company
1405 Canal Bldg.
Vice-President and Program Chm. - B. E. Bremer
The Texas Company, P.O. Box 252
Secretary-Treasurer - - - R. R. Copeland, Jr.
The California Company, 1818 Canal Bldg.

Meets the first Monday of every month, October-May inclusive, 7:30 P.M., St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

LOUISIANA

THE SHREVEPORT GEOLOGICAL SOCIETY
SHREVEPORT, LOUISIANA

President - - - - - - - - - R. M. Wilson
Ohio Oil Company, Drawer 1129, Zone 91
Vice-President - - - - - - - - E. P. Ogier
c/o W. C. Spooner, Box 1195, Zone 90
Secretary-Treasurer - - - - - L. H. Meltzer
Union Producing Co., Box 1407, Zone 92

Meets the first Monday of every month, September to May, inclusive, 7:30 P.M., Criminal Court Room, Caddo Parish Court House. Special meetings and dinner meetings by announcement.

LOUISIANA

SOUTH LOUISIANA GEOLOGICAL SOCIETY
LAKE CHARLES, LOUISIANA

President - - - - - - - - - - C. B. Roach
Shell Oil Company, Inc., Box 136
Vice-President - - - - - - - P. S. Schoeneck
Atlantic Refining Company
Secretary - - - - - - - - - Ben F. Morgan
Stanolind Oil and Gas Company
Treasurer - - - - - - - . Robert N. Watson
Atlantic Refining Company, Box 895

Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

MICHIGAN

MICHIGAN GEOLOGICAL SOCIETY

President - - - - - - Edward J. Baltrusaitis
Gulf Refining Company, Box 811, Saginaw
Vice-President - - - - - Raymond S. Hunt
Consulting, 405 S. Main, Mt. Pleasant
Secretary-Treasurer - - - - Thomas S. Knapp
The Chartiers Oil Co., Box 227, Mt. Pleasant
Business Manager - - - - - - Lee S. Miller
Michigan Geological Survey,
Capitol Savings and Loan Bldg., Lansing

Meetings: Bi-monthly from November to April at Lansing. Afternoon session at 3:00, informal dinner at 6:30 followed by discussions. (Dual meetings for the duration.) Visiting geologists are welcome.

MISSISSIPPI

MISSISSIPPI GEOLOGICAL SOCIETY
JACKSON, MISSISSIPPI

President - - - - - - - - L. R. McFarland
Magnolia Petroleum Company

Vice-President - - - - - - - J. B. Storey
Union Producing Company

Secretary-Treasurer - - - - Frederic F. Mellen
British-American Oil Producing Company
1007 Tower Building

Meetings: First and third Thursdays of each month, from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

OKLAHOMA

ARDMORE GEOLOGICAL SOCIETY
ARDMORE, OKLAHOMA

President - - - - - - - - - John Marshall
The Texas Company, Box 539

Vice-President - - - - - - Frank Neighbor
Sinclair Prairie Oil Company

Secretary-Treasurer - - - - - - - S. L. Rose
618 Simpson Building

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

OKLAHOMA

OKLAHOMA CITY GEOLOGICAL SOCIETY
OKLAHOMA CITY, OKLAHOMA

President - - - - - - - - - E. G. Dahlgren
Interstate Oil Compact Commission
State Capitol

Vice-President - - - - - Theodore G. Glass
Sinclair Prairie Oil Company
703 Colcord Building

Secretary-Treasurer - - - - - C. E. Hamilton
Consolidated Gas Utilities Corporation
814 Braniff Building

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every Thursday, at 12:00 noon. Y.W.C.A. Cafeteria.

SHAWNEE GEOLOGICAL SOCIETY
SHAWNEE, OKLAHOMA

President - - - - - - - - - - Allen Ehlers
Carter Oil Company, Box 1151, Seminole

Vice-President - - - - - - John P. Lukens
Oklahoma Seismograph, 1103 North Philadelphia

Secretary-Treasurer - - - - Marcelle Mousley
Atlantic Refining Company, Box 169

Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

TULSA GEOLOGICAL SOCIETY
TULSA, OKLAHOMA

President - - - - - - - - - J. V. Howell
1506 Philtower

1st Vice-President - - - - - - - W. H. Butt
Atlantic Refining Company

2nd Vice-President - - - - W. Reese Dillard
Consulting

Secretary-Treasurer - - - - - - - V. G. Hill
Stanolind Oil and Gas Company, Box 591

Editor - - - - - - - - - - - Roy L. Ginter
U. S. Geological Survey

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Tuesday (October-May), Bradford Hotel.

TEXAS

CORPUS CHRISTI GEOLOGICAL SOCIETY
CORPUS CHRISTI, TEXAS

President - - - - - - - - - - Ira H. Stein
Continental Oil Company, 604 Driscoll Building

Vice-President - - - - - Henry D. McCallum
Humble Oil and Refining Company

Secretary-Treasurer - - - - Elsie B. Chalupnik
Barnsdall Oil Company, 904 Driscoll Building

Regular luncheons, every Wednesday, Petroleum Room, Plaza Hotel, 12:05 P.M. Special night meetings, by announcement.

DALLAS PETROLEUM GEOLOGISTS
DALLAS, TEXAS

President - - - - - - - - - Henry C. Cortes
Magnolia Petroleum Company

Vice-President - - - - - - - Cecil H. Green
Geophysical Service, Inc.

Secretary-Treasurer - - - - Willis G. Meyer
DeGolyer and MacNaughton, Continental Building

Executive Committee - - - Henry J. Morgan
Atlantic Refining Company

Meetings: Monthly luncheons by announcement. Special night meetings by announcement.

TEXAS

EAST TEXAS GEOLOGICAL SOCIETY

TYLER, TEXAS

President - - - - - - - - J. H. McGuirt
Magnolia Petroleum Company, Box 780

Vice-President - - - - - R. M. Trowbridge
Trowbridge Sample Service

Secretary-Treasurer - - - - - Russell Farmer
Stanolind Oil and Gas Company, Box 660

Meetings: Regular meetings at 7:30 P.M., the second Monday, each month, City Hall.
Luncheons: Noon, fourth Monday, each month, Blackstone Hotel.

HOUSTON GEOLOGICAL SOCIETY

HOUSTON, TEXAS

President - - - - - - - W. B. Milton, Jr.
Gulf Oil Corporation, Box 2100

Vice-President - - - - - - - W. B. Moore
Atlantic Refining Company, Box 1346

Secretary - - - - - - - Charles H. Sample
J. M. Huber Corporation, 721 Bankers Mortgage Building

Treasurer - - - - - - - Homer A. Noble
Magnolia Petroleum Company, Box 111

Regular meeting held the first and third Thursdays at noon (12 o'clock), Mezzanine floor, Texas State Hotel. For any particulars pertaining to the meetings write or call the secretary.

SOUTH TEXAS GEOLOGICAL SOCIETY

SAN ANTONIO, TEXAS

President - - - - - - - Robert N. Kolm
Atlantic Refining Co., 1742 Milam Building

Vice-President - - - - - Donald O. Chapell
Transwestern Oil Co., 1600 Milam Building

Secretary-Treasurer - - - Robert D. Mebane
Saltmount Oil Co., 916 Milam Building

Meetings: One regular meeting each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

FORT WORTH GEOLOGICAL SOCIETY

FORT WORTH, TEXAS

President - - - - - Joseph H. Markley, Jr.
The Texas Company, Box 1720

Vice-President - - - - - - James L. Morris
The Pure Oil Company, Box 2107

Secretary-Treasurer - - - Spencer R. Normand
Independent Exploration Company
2210 Ft. Worth Natl. Bank Bldg.

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

NORTH TEXAS GEOLOGICAL SOCIETY

WICHITA FALLS, TEXAS

President - - - - - - - - - Donald Kelly
The Texas Company

Vice-President - - - William Lloyd Haseltine
Magnolia Petroleum Co., Box 239

Secretary-Treasurer - - - David T. Richards
Shell Oil Co., Inc., Box 2010

Luncheons and evening programs will be announced.

WEST TEXAS GEOLOGICAL SOCIETY

MIDLAND, TEXAS

President - - - - - - - - Robert I. Dickey
Forest Development Corporation

Vice-President - - - - - George R. Gibson
Richfield Oil Corporation

Secretary-Treasurer - - - - - - Jane Ferrell
Magnolia Petroleum Company, Box 633

Meetings will be announced

WEST VIRGINIA

THE APPALACHIAN GEOLOGICAL SOCIETY

CHARLESTON, WEST VIRGINIA
P. O. Box 2385

President - - - - - - - Douglas Rogers, Jr.
South Penn Natural Gas Company, Parkersburg

Vice-President - - - - - - Veleair C. Smith
Kanawha Valley Bank Building

Secretary-Treasurer - - - - - Charles E. Stout
United Fuel Gas Company, Box 1273

Editor - - - - - - - - H. J. Simmons, Jr.
Godfrey L. Cabot, Inc., Box 1473

Meetings: Second Monday, each month, except June, July, and August, at 6:30 P.M., Kanawha Hotel.

THE SOCIETY OF EXPLORATION GEOPHYSICISTS

President - - - - - - William M. Rust, Jr.
Humble Oil & Refining Company, Houston, Texas

Vice-President - - - - - - Henry C. Cortes
Magnolia Petroleum Company, Dallas, Texas

Editor - - - - - - - - Joseph A. Sharpe
Stanolind Oil and Gas Company, Tulsa, Oklahoma

Secretary-Treasurer - - - - W. Harlan Taylor
Petty Geophysical Engineering Company
1449 Esperson Bldg., Houston, Texas

Past-President - - - - - - - R. D. Wyckoff
Gulf Research and Development Company
Pittsburgh, Pennsylvania

Business Manager - - - - - - J. F. Gallie
P.O. Box 410, El Dorado, Arkansas

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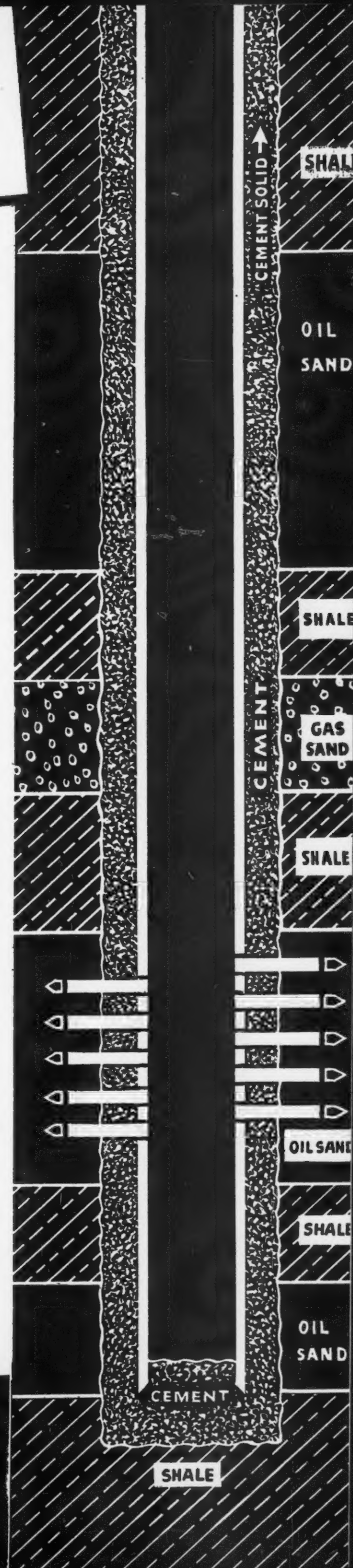


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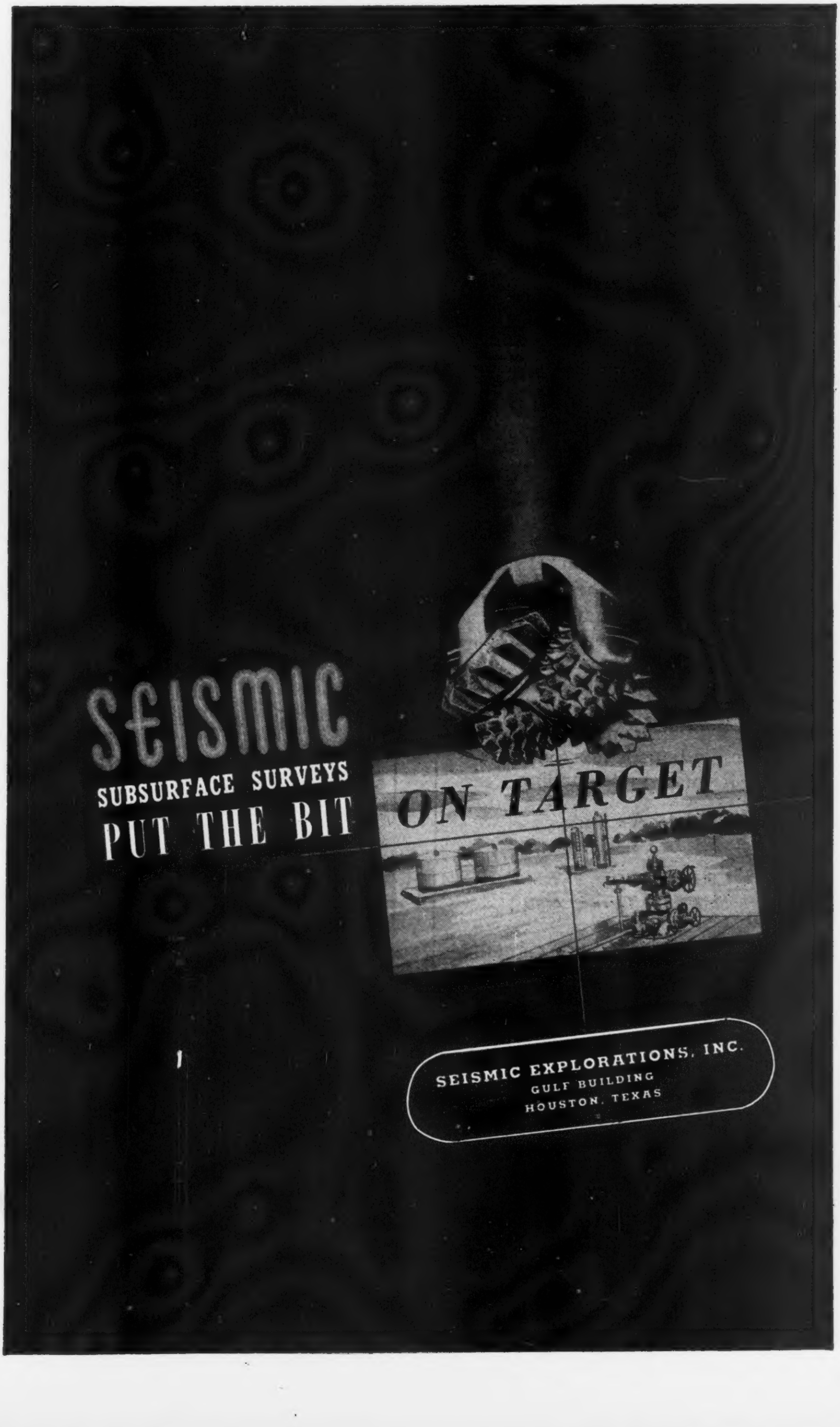
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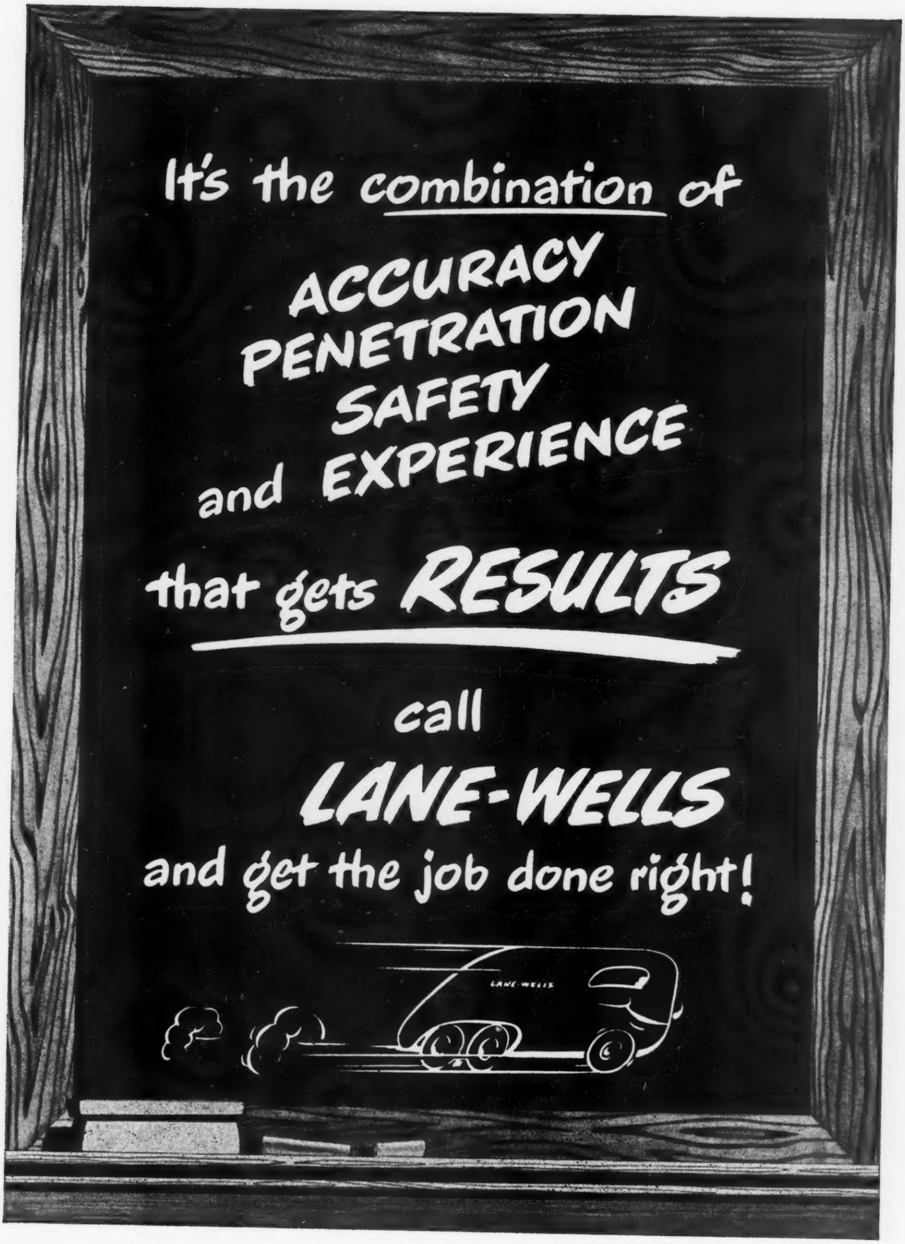
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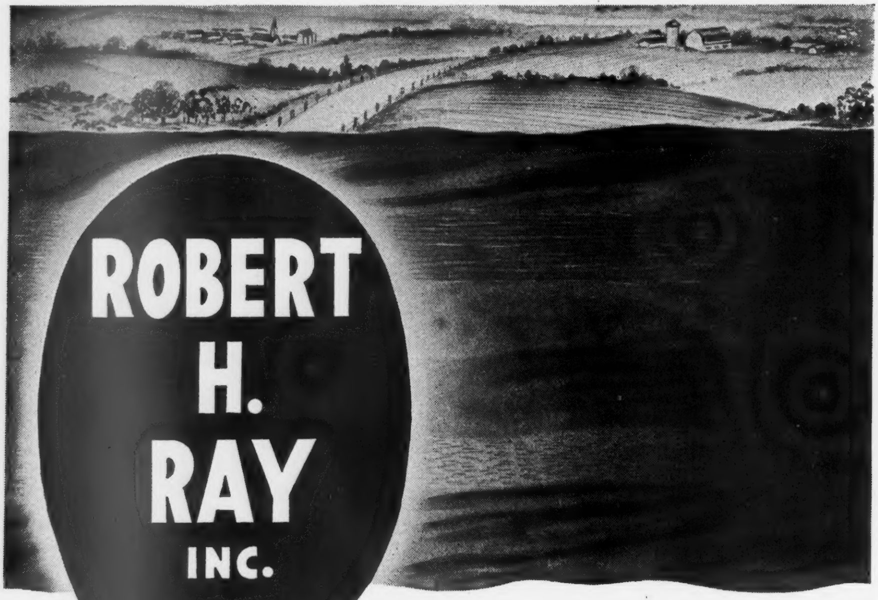
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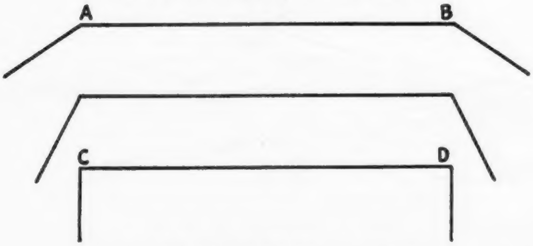

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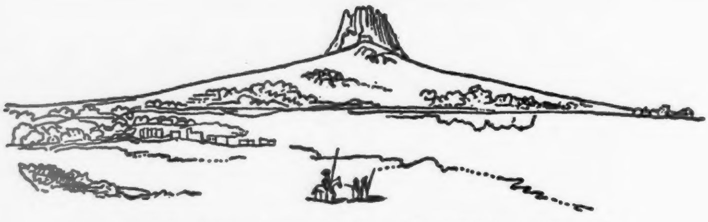
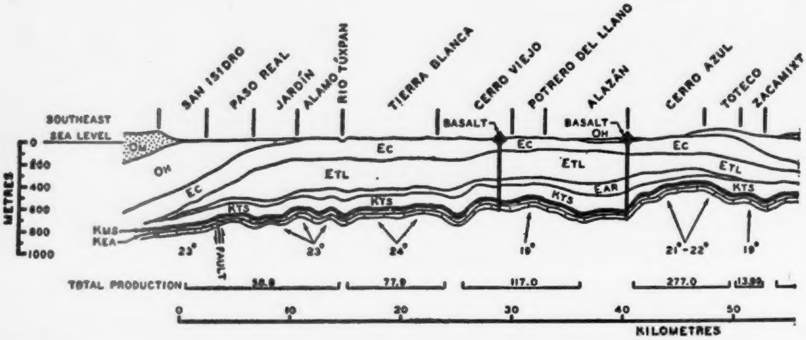
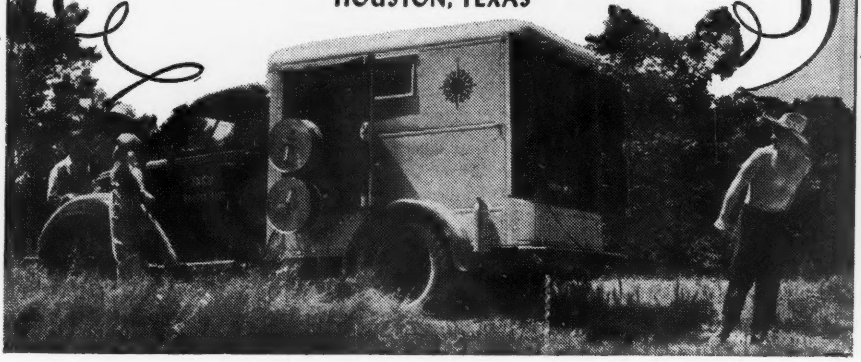
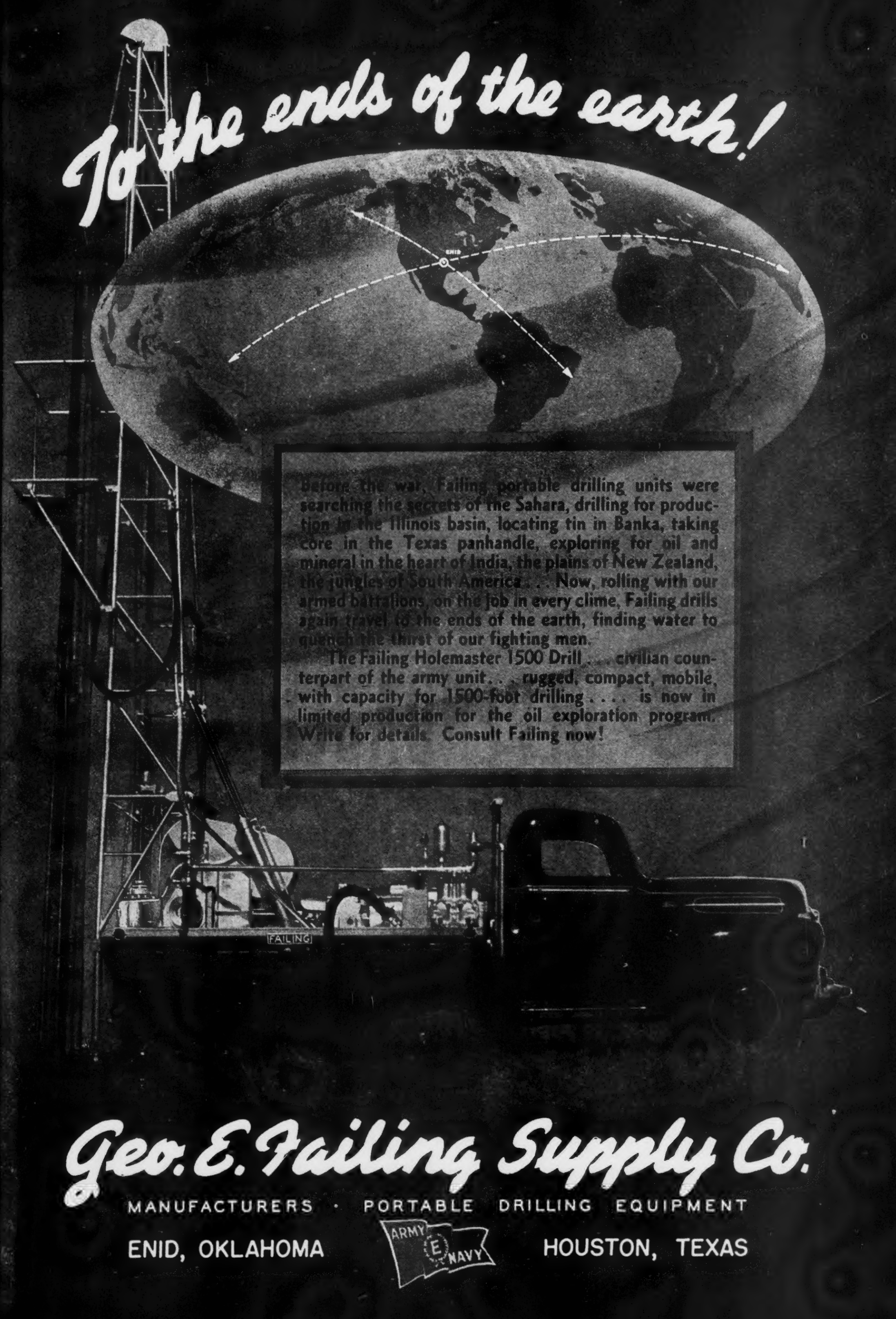


FIG. 20.—Cerro Bernal, volcanic plug. (Reproduction of sketch by Captain G. F. Lyon, 1828; redrawn by F. S. Howell.)



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